GB2355316

Title:
Computer aided method for generating topological features for manual input in generating numerically controlled machining program for a workpiece

Abstract:
The method, associated system and associated program produce numerically controlled machining instructions for converting a workpiece (shown dashed) to a physical object. A solid model of the object and a solid model of the workpiece are provided using graphical software, and the model of the object is combined with the model of the workpiece to produce the numerical control model shown depicting volume portions of the workpiece to be removed to form the object. A plurality of topological feature types 36 - 64 are provided, and the volume portions to be removed are partitioned into a plurality of machining features, each of which is produced by a human user choosing one of the plurality of feature types and a surface of the numerical model to associate the two and define each machining feature. Tool paths for machining each of the machining features are then provided.

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(51) INT CL^7
G05B 19/4093

(52) UK CL (Edition S)
G3N NGBC4 N289 N291 N383X N404

(56) Documents Cited
EP 0604661 A US 5465215 A

(58) Field of Search
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ONLINE: EPODOC, JAPIO, WPI

(54) Abstract Title
Computer aided method for generating topological features for manual input in generating numerically controlled machining program for a workpiece

(57) The method, associated system and associated program produce numerically controlled machining instructions for converting a workpiece (shown dashed) to a physical object. A solid model of the object and a solid model of the workpiece are provided using graphical software, and the model of the object is combined with the model of the workpiece to produce the numerical control model shown depicting volume portions of the workpiece to be removed to form the object. A plurality of topological feature types 36 - 64 are provided, and the volume portions to be removed are partitioned into a plurality of machining features, each of which is produced by a human user choosing one of the plurality of feature types and a surface of the numerical model to associate the two and define each machining feature. Tool paths for machining each of the machining features are then provided.

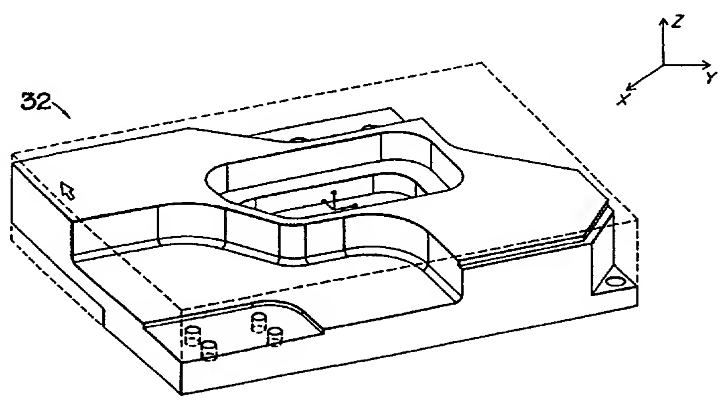


FIG.3.

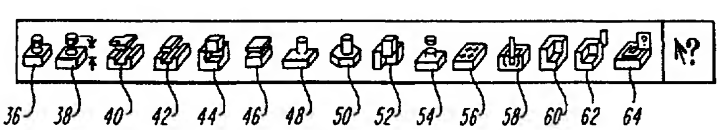


FIG.4.

GB 2 355 316 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

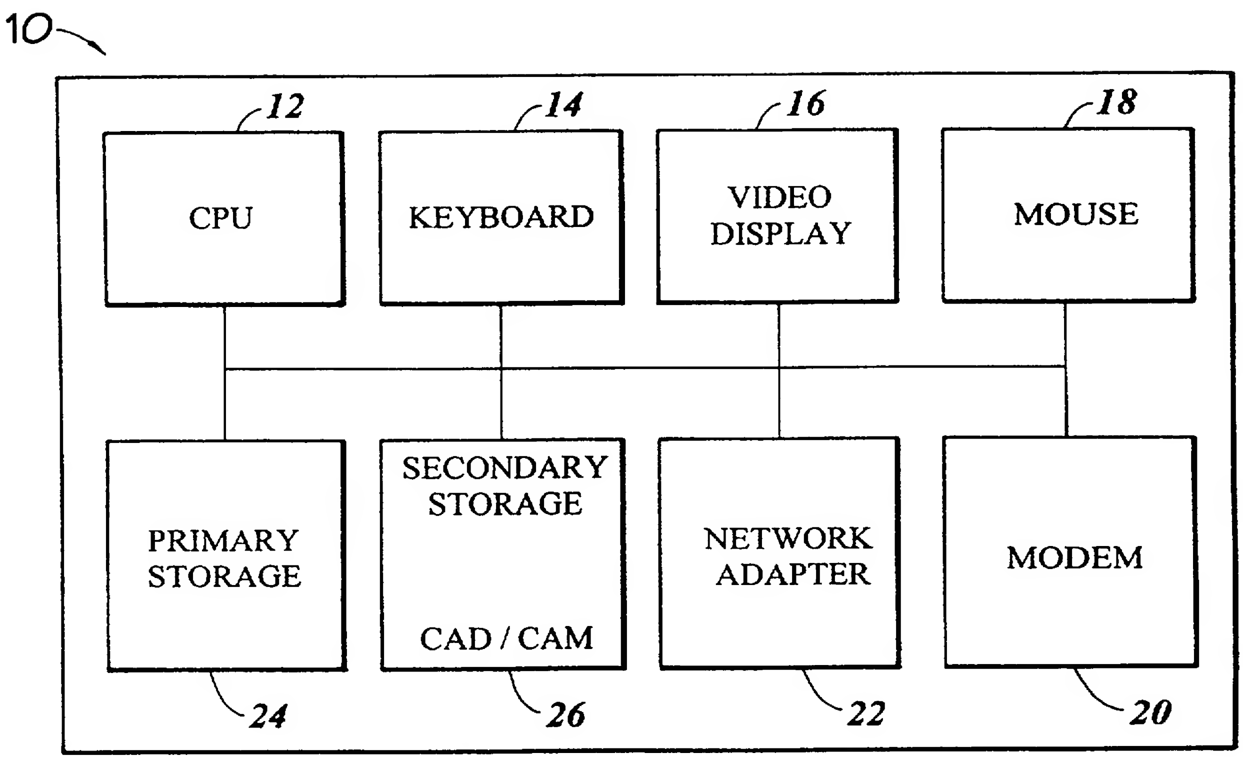

10
CPU
12
KEYBOARD
14
VIDEO DISPLAY
16
MOUSE
18
PRIMARY STORAGE
24
SECONDARY STORAGE
CAD / CAM
26
NETWORK ADAPTER
22
MODEM
20

FIG.1.

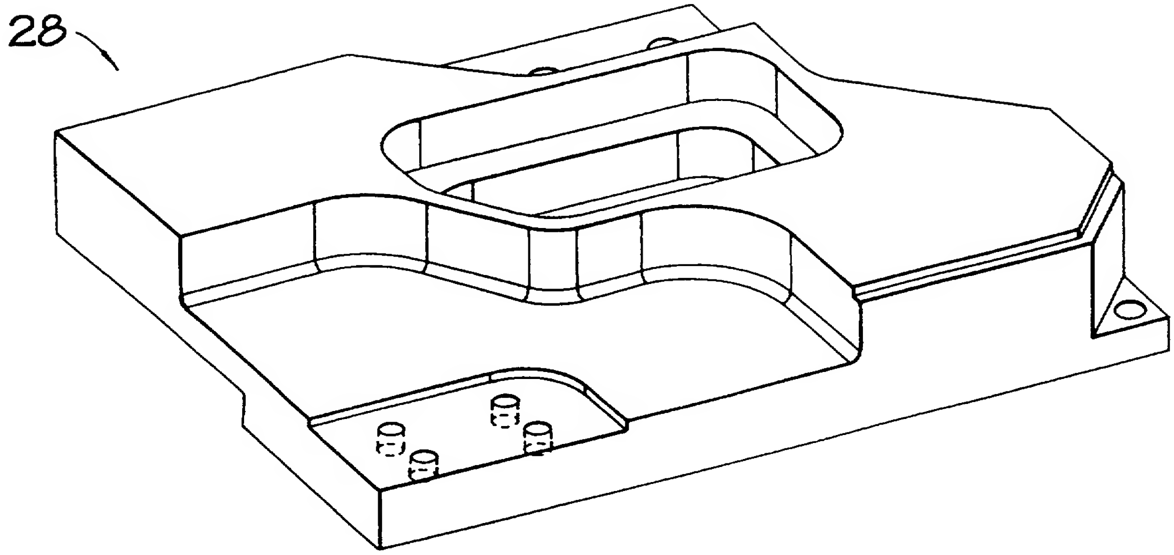


FIG.2A.

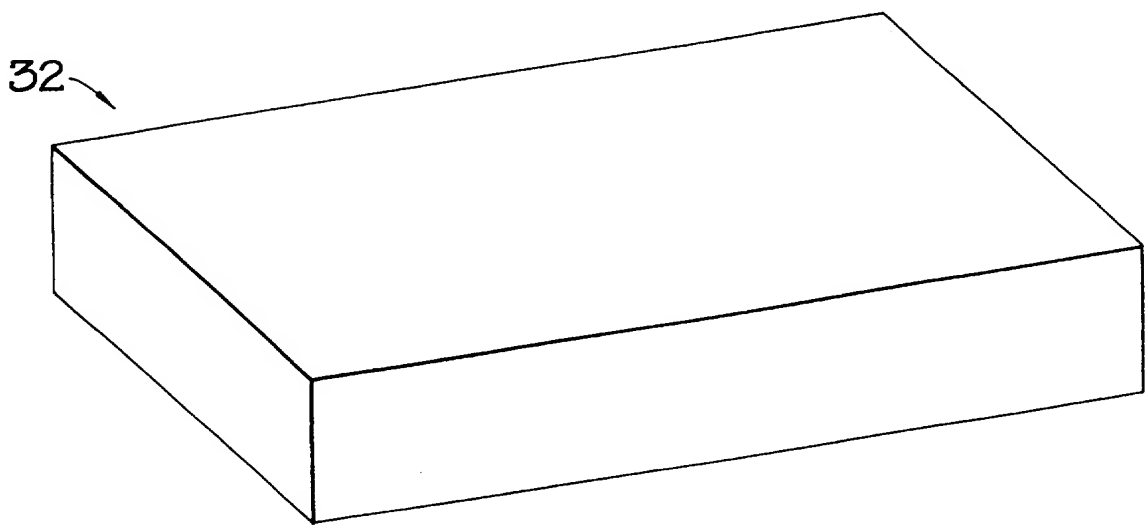


FIG.2B.

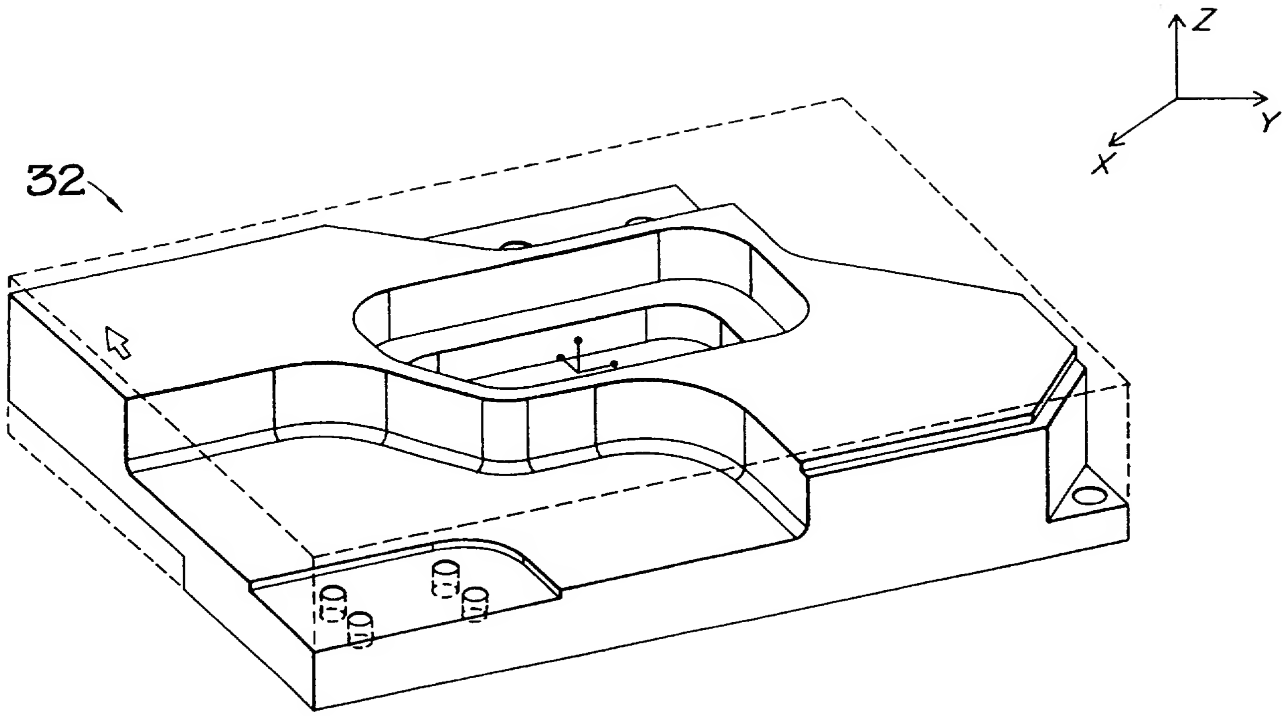


FIG.3.

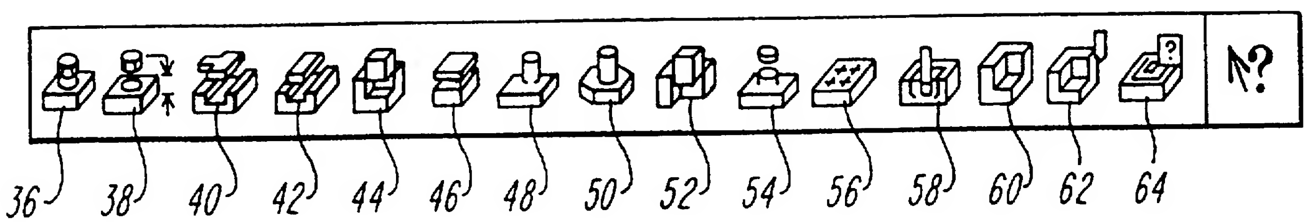
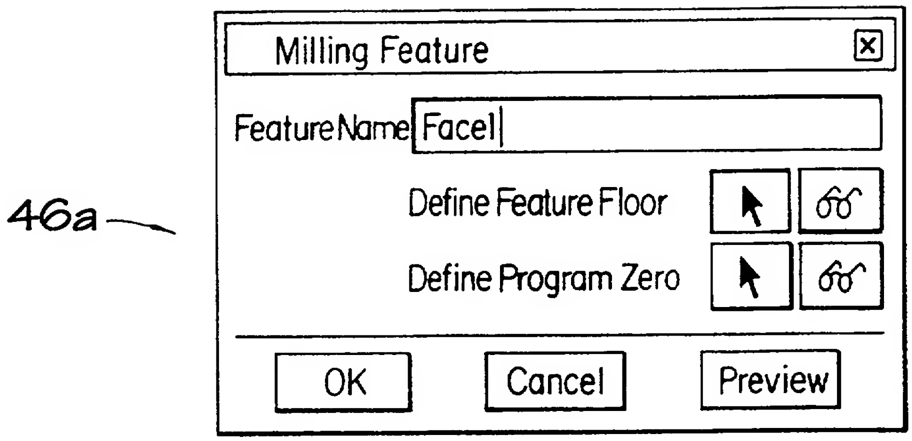
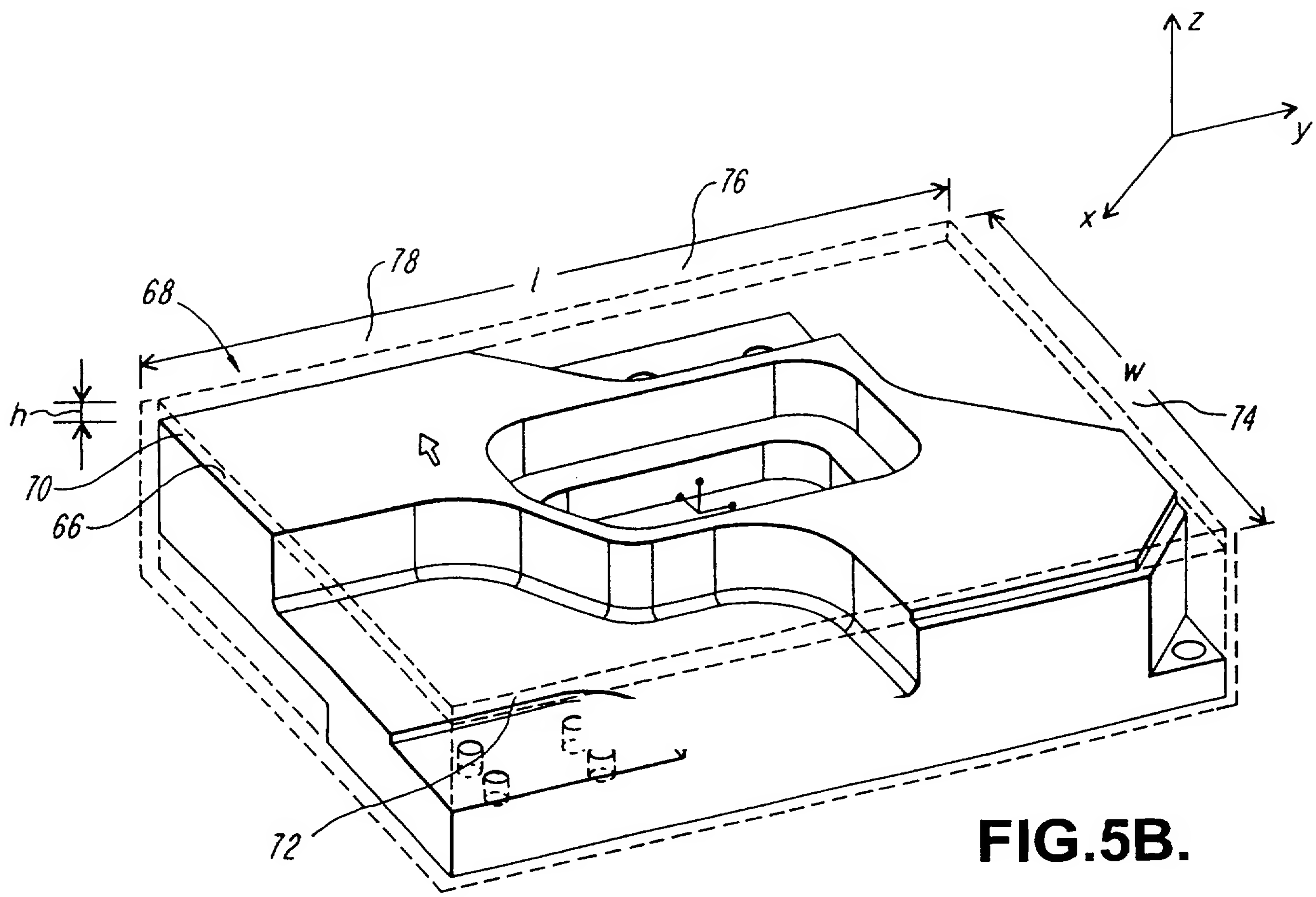


FIG.4.



46a
Milling Feature
Feature Name
Face1
Define Feature Floor
Define Program Zero
OK
Cancel
Preview

FIG.5A.



z
y
x
76
78
68
l
w
74
h
70
66
72

FIG.5B.

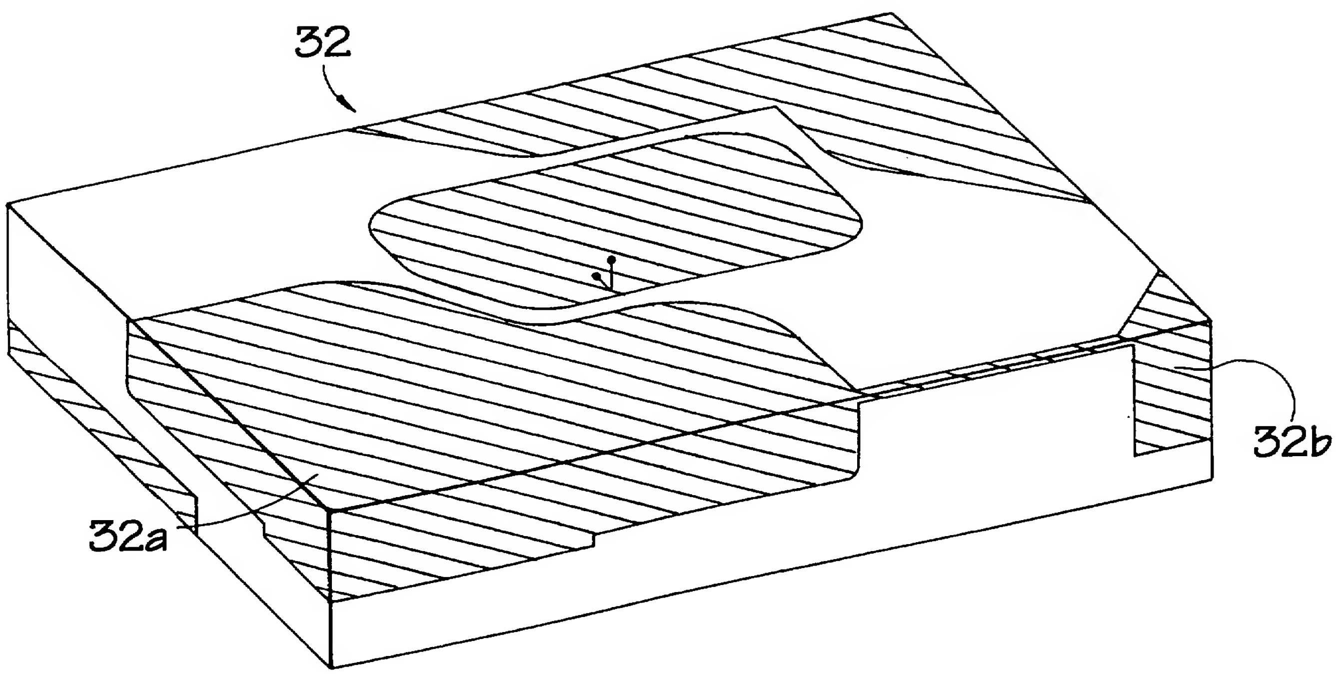


FIG.5C.

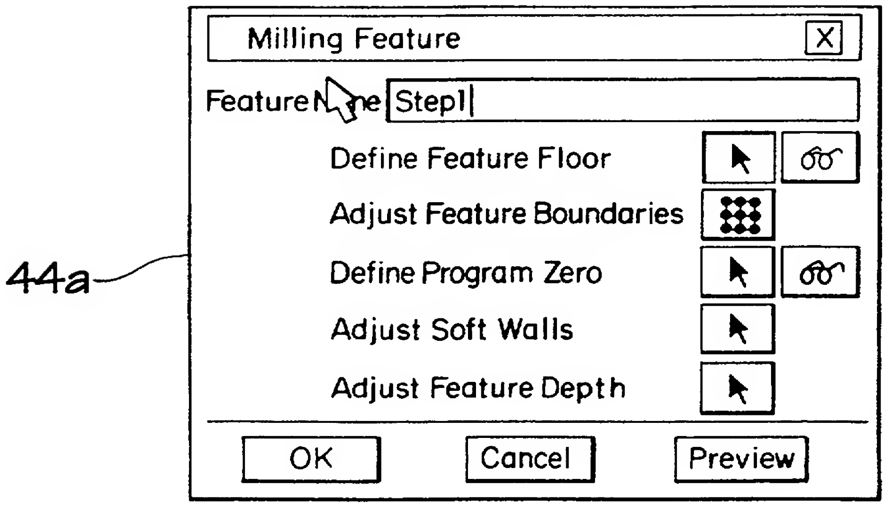

44a
Milling Feature
X
Feature Name
Step1
Define Feature Floor
Adjust Feature Boundaries
Define Program Zero
Adjust Soft Walls
Adjust Feature Depth
OK
Cancel
Preview

FIG.6A.

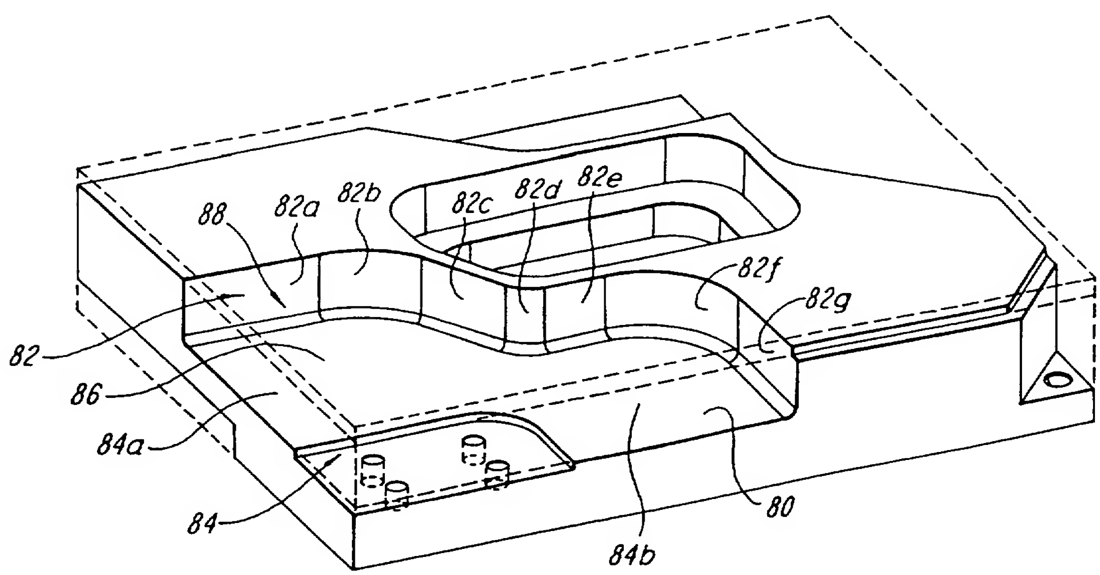

88
82a
82b
82c
82d
82e
82f
82g
82
86
84a
84
84b
80

FIG.6B.

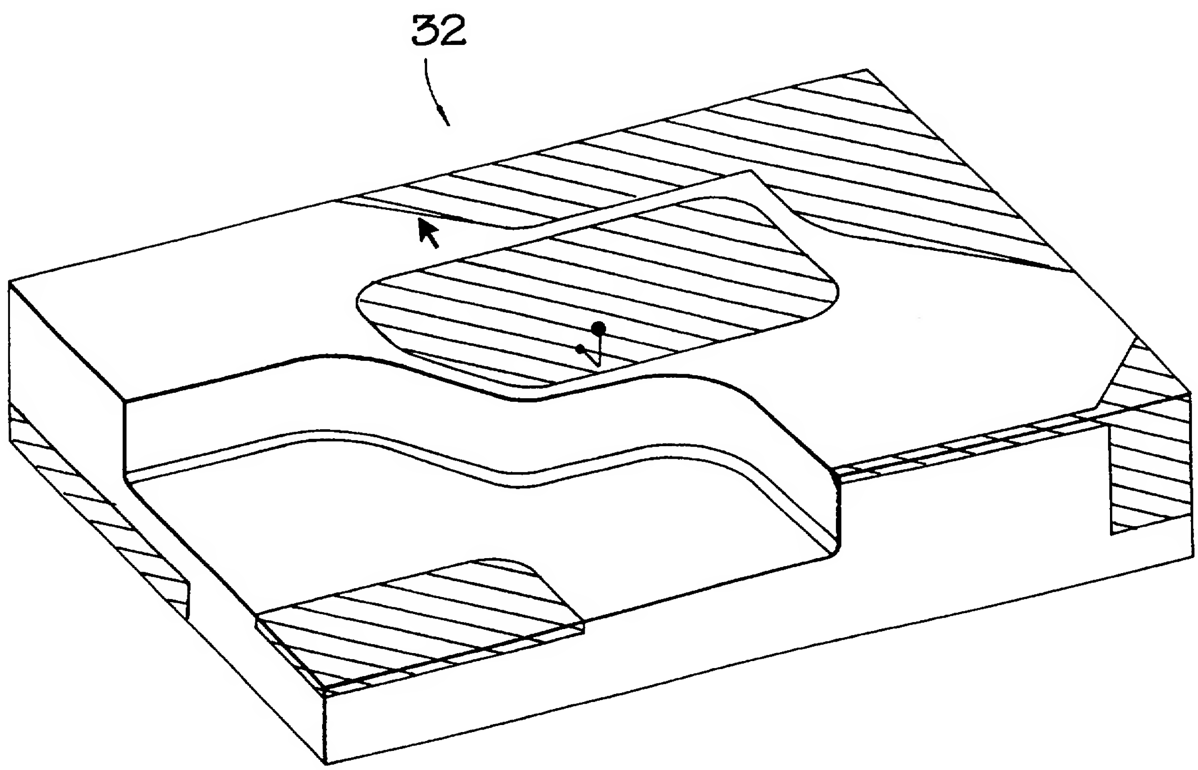


FIG.6C.

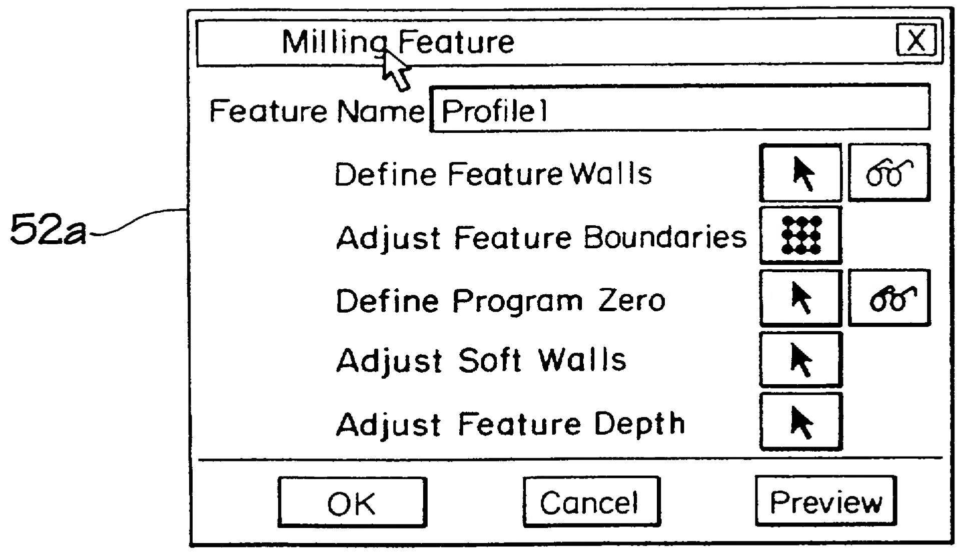

52a
Milling Feature
X
Feature Name
Profile1
Define Feature Walls
Adjust Feature Boundaries
Define Program Zero
Adjust Soft Walls
Adjust Feature Depth
OK
Cancel
Preview

FIG.7A.

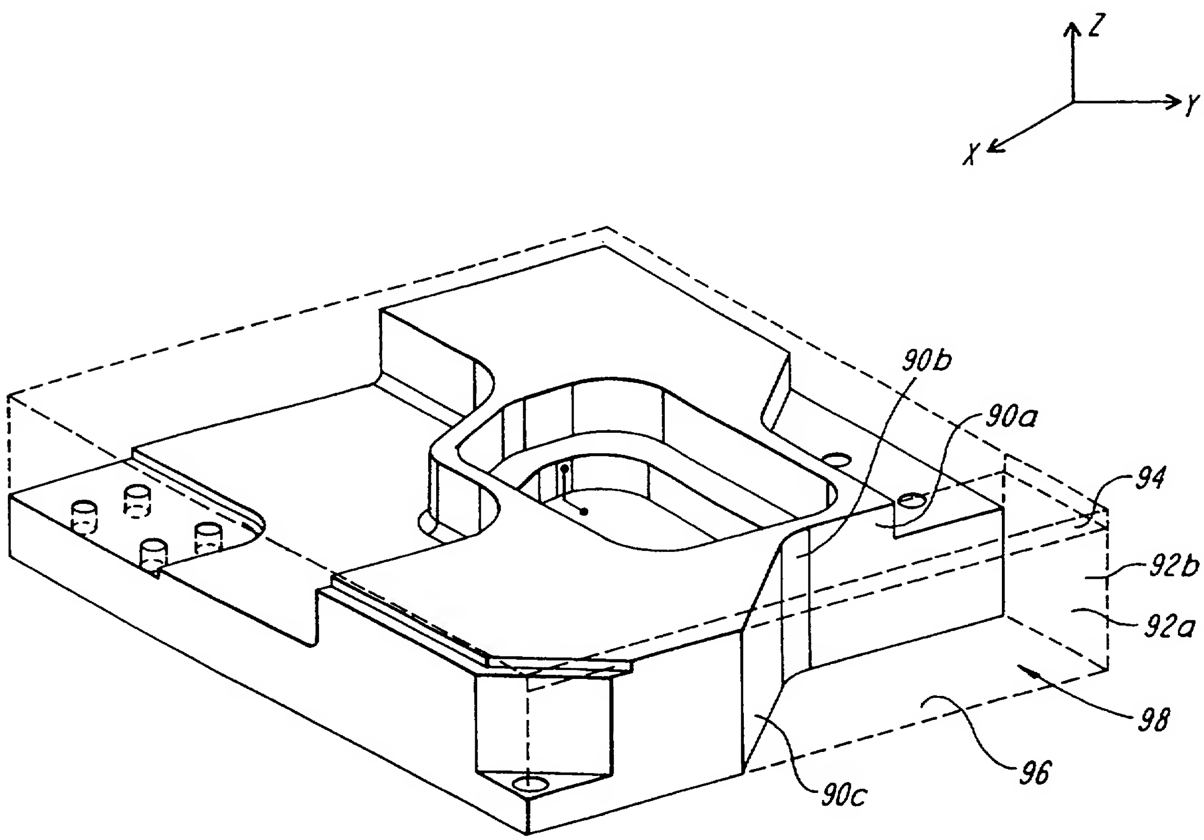

Z
Y
X
90b
90a
94
92b
92a
98
96
90c

FIG.7B.

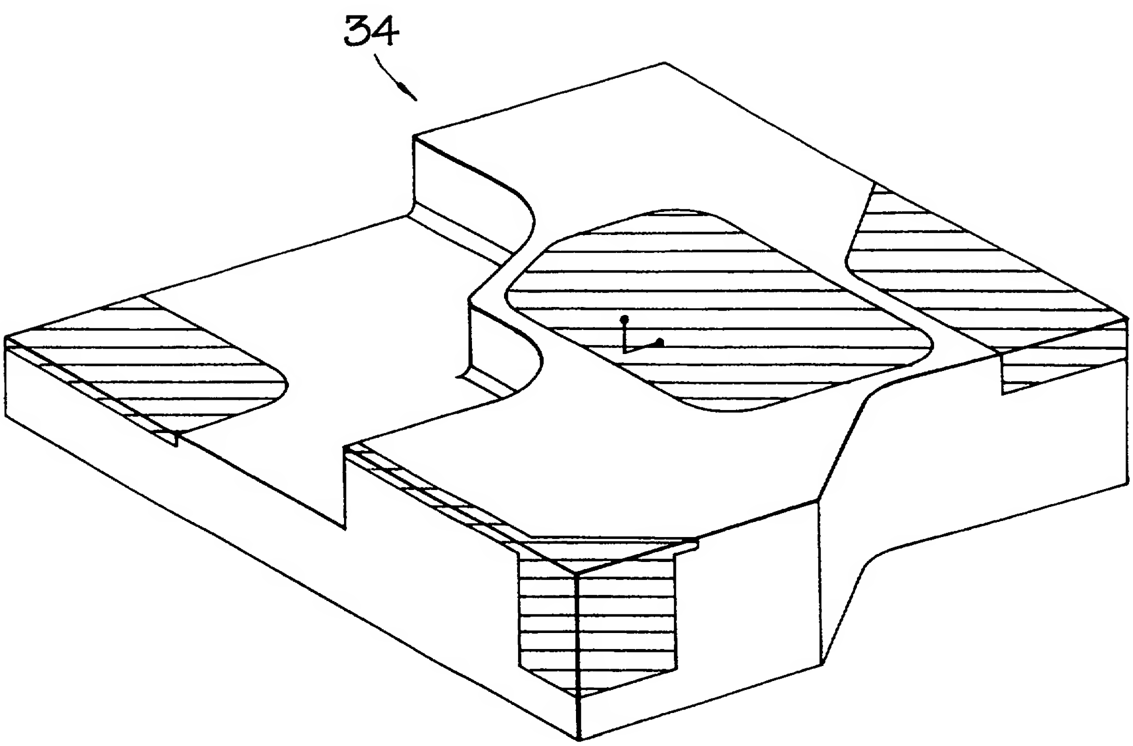


FIG.7C.

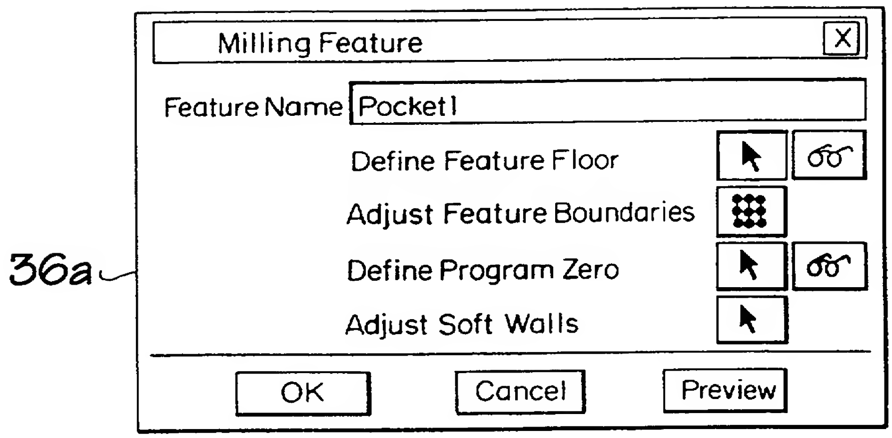

36a
Milling Feature
X
Feature Name
Pocket1
Define Feature Floor
Adjust Feature Boundaries
Define Program Zero
Adjust Soft Walls
OK
Cancel
Preview

FIG.8A.

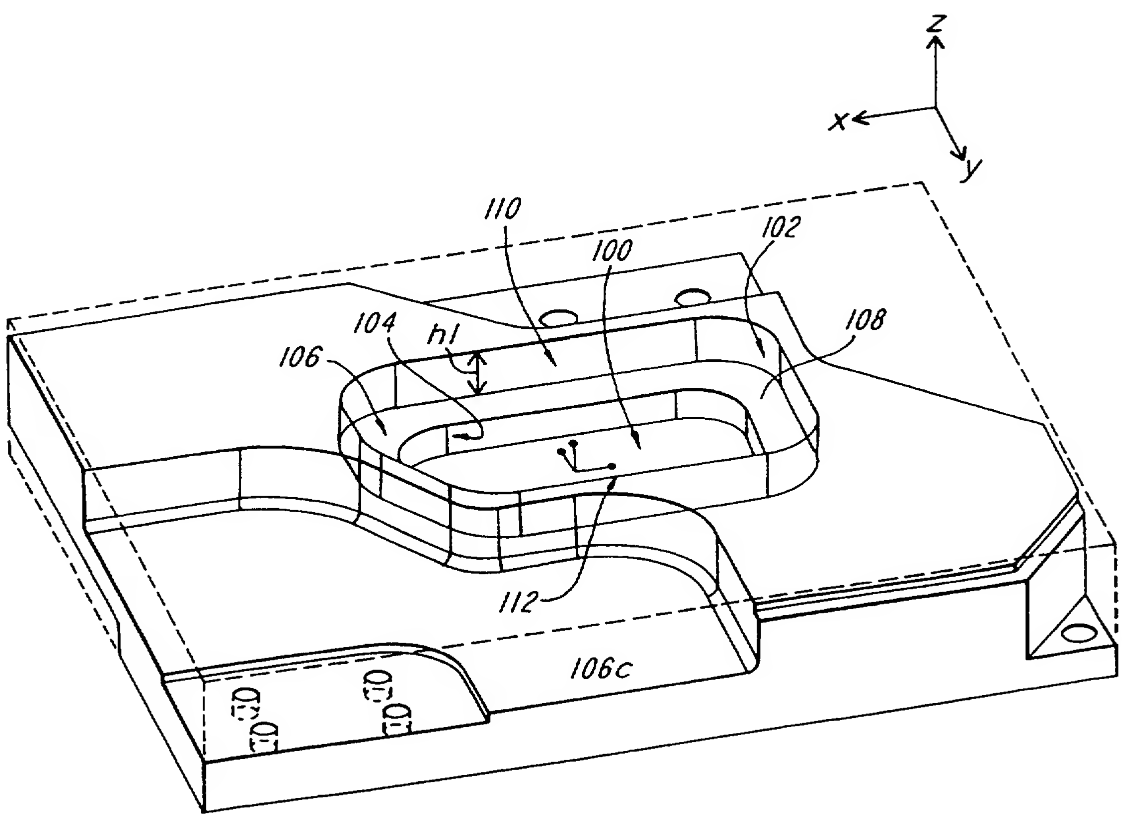

z
x
y
110
100
102
108
104
h1
106
112
106c

FIG.8B.

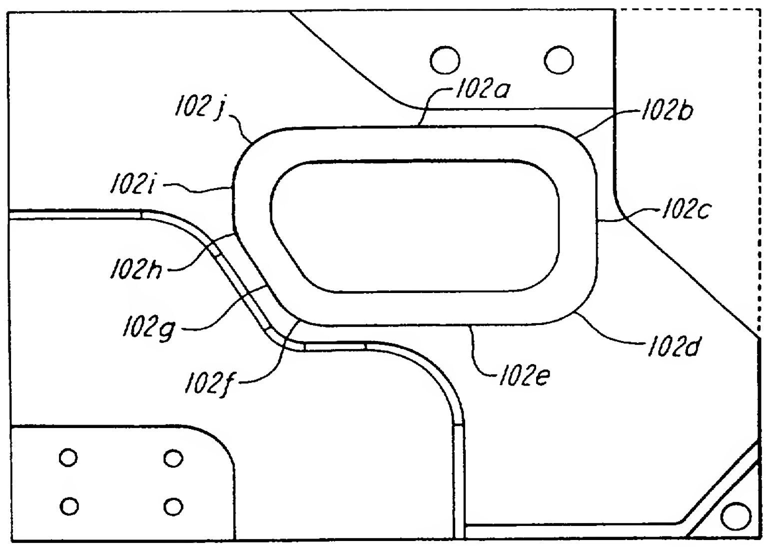


FIG.8C.

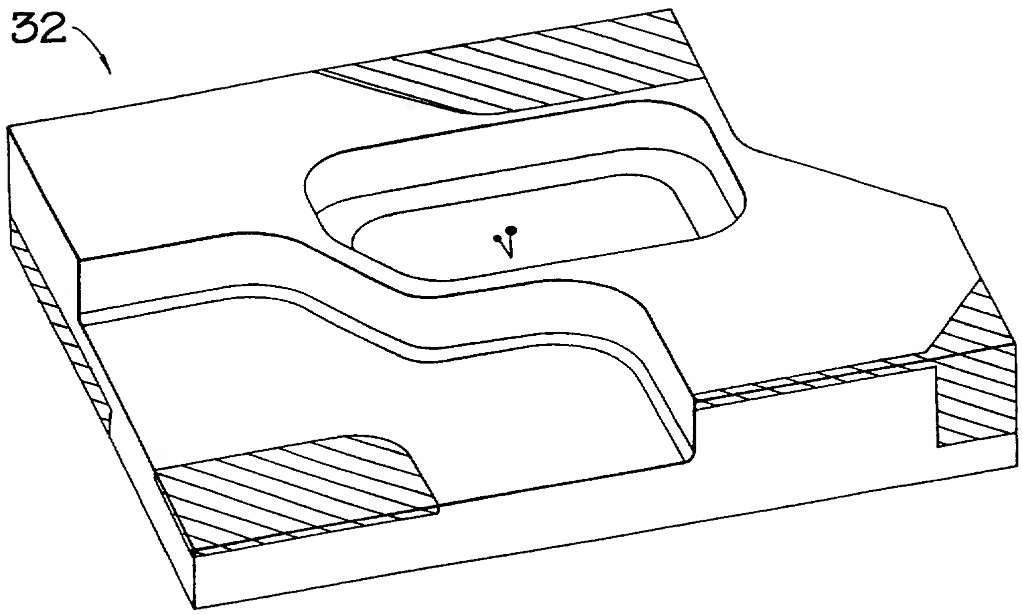


FIG.8D.

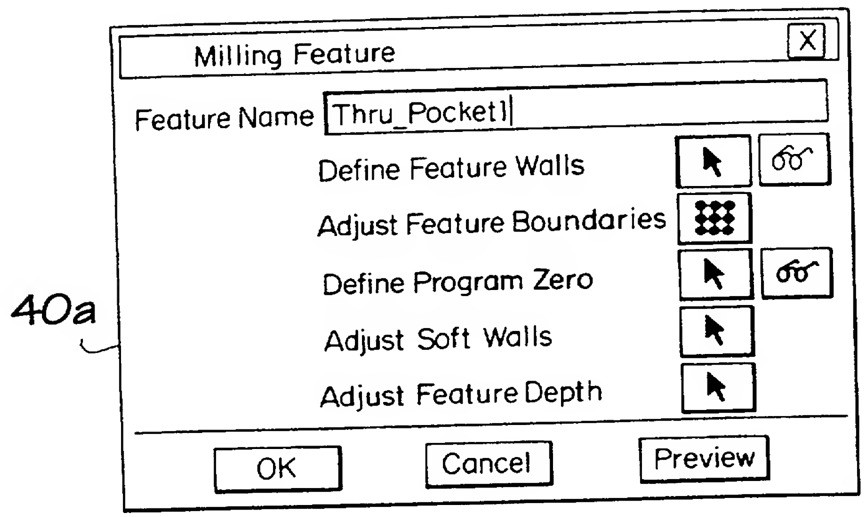

40a
Milling Feature
X
Feature Name
Thru_Pocket1
Define Feature Walls
Adjust Feature Boundaries
Define Program Zero
Adjust Soft Walls
Adjust Feature Depth
OK
Cancel
Preview

FIG.9A.

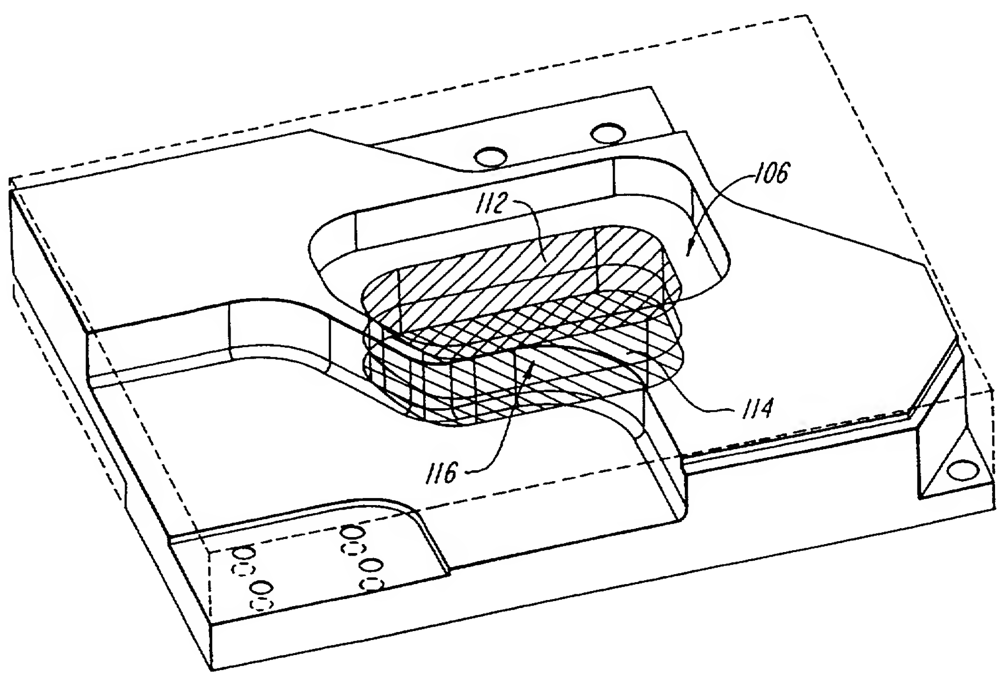

106
112
114
116

FIG.9B.

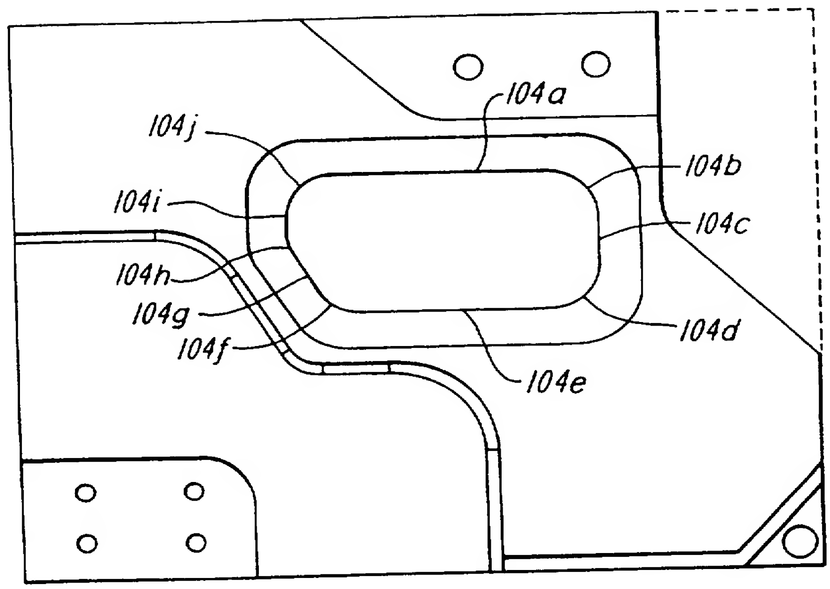


FIG.9C.

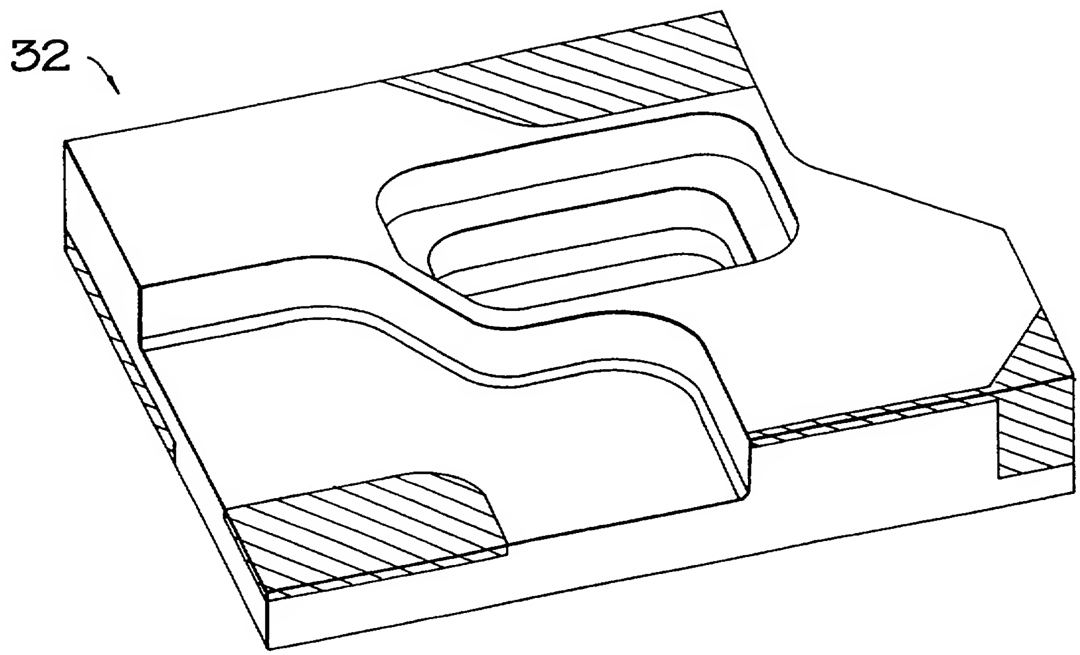


FIG.9D.

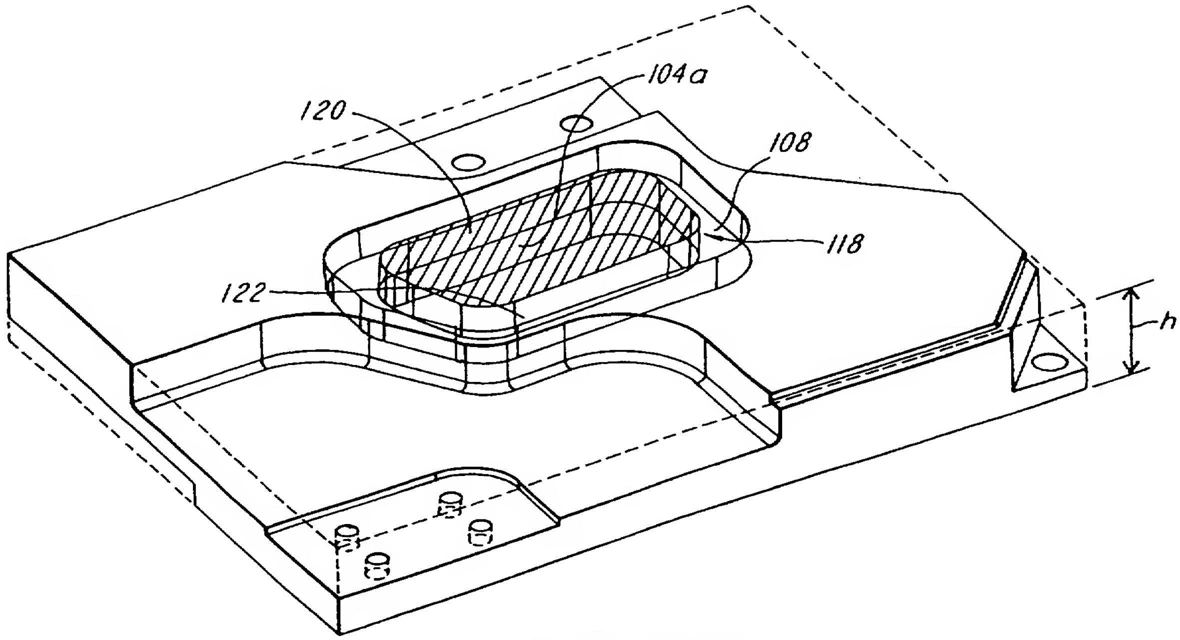


FIG.10A.

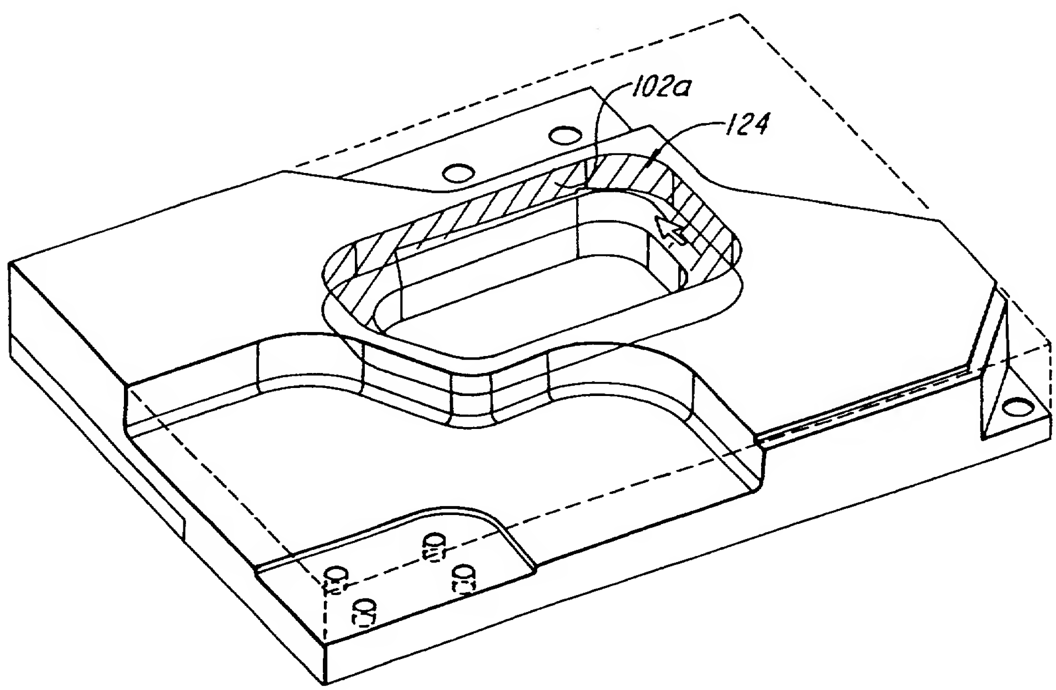


FIG.10B.

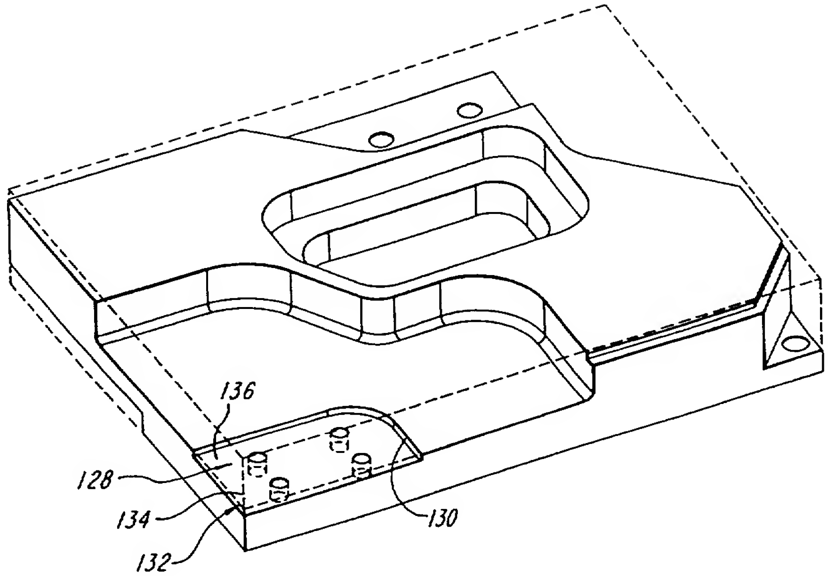


FIG.11A.

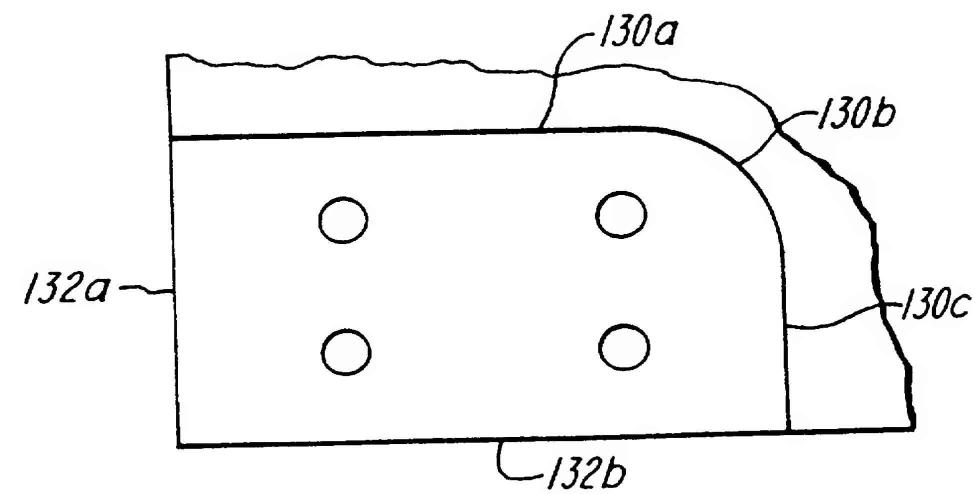


FIG.11B.

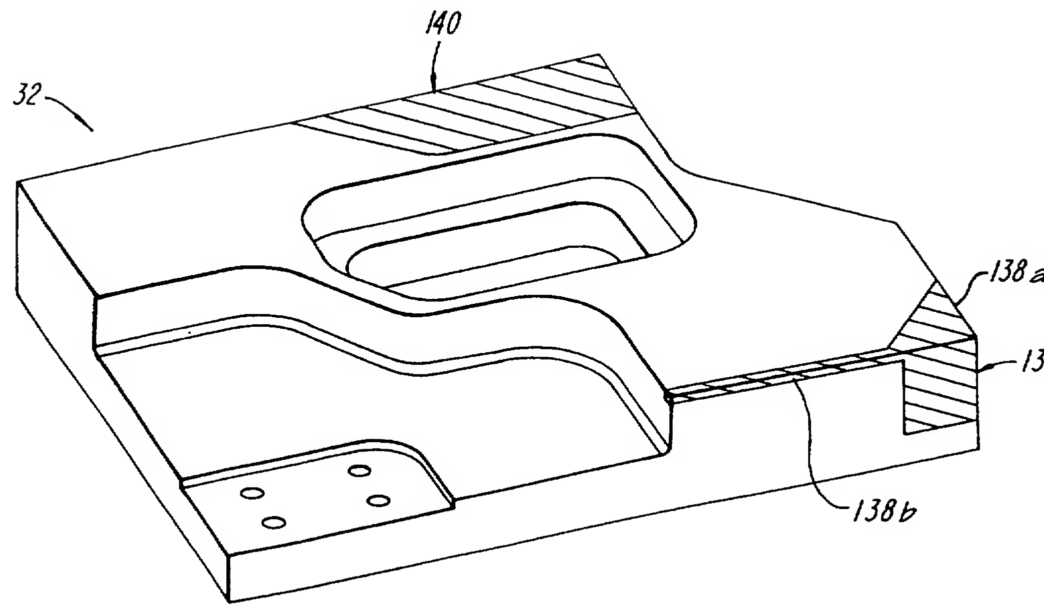


FIG.11C.

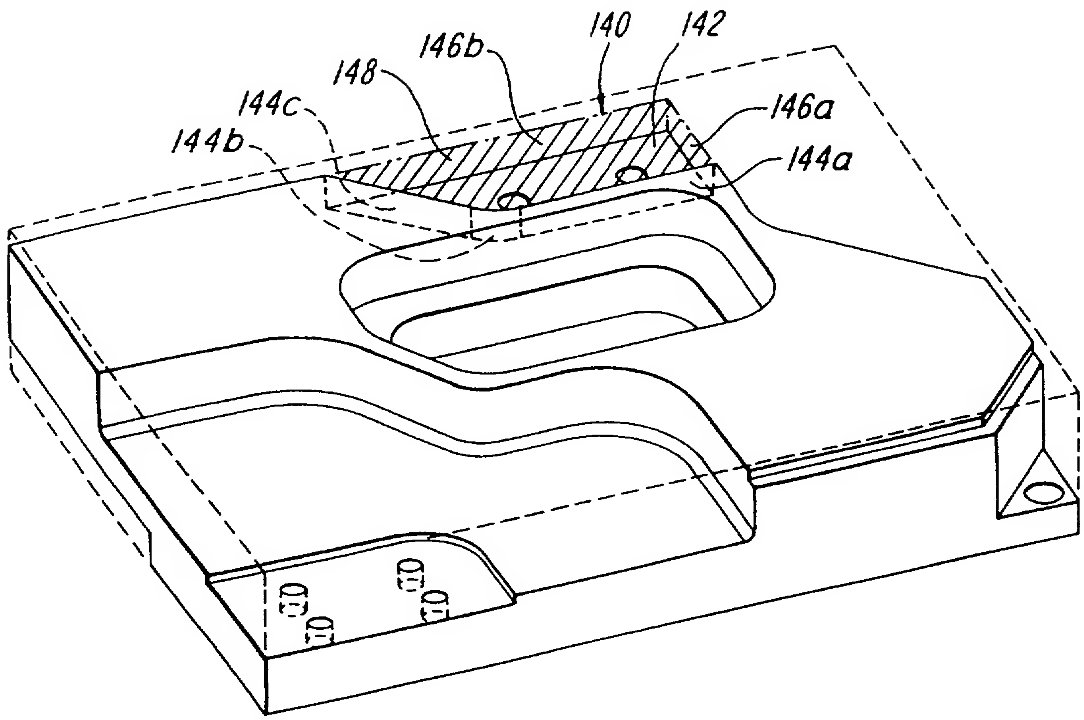


FIG.12A.

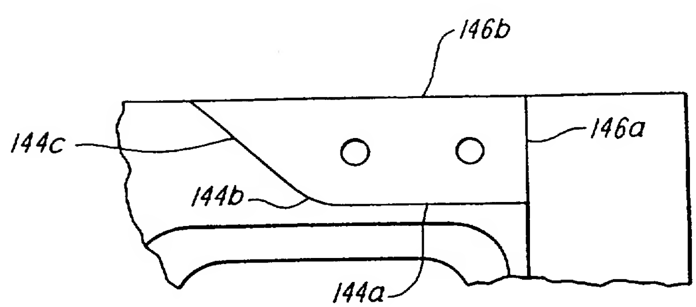


FIG.12B.

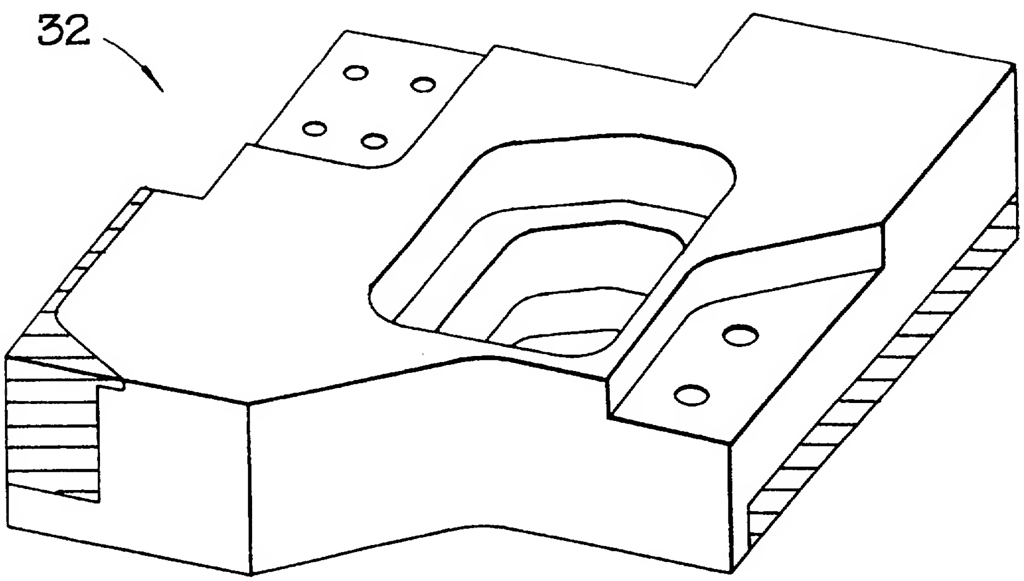


FIG.12C.

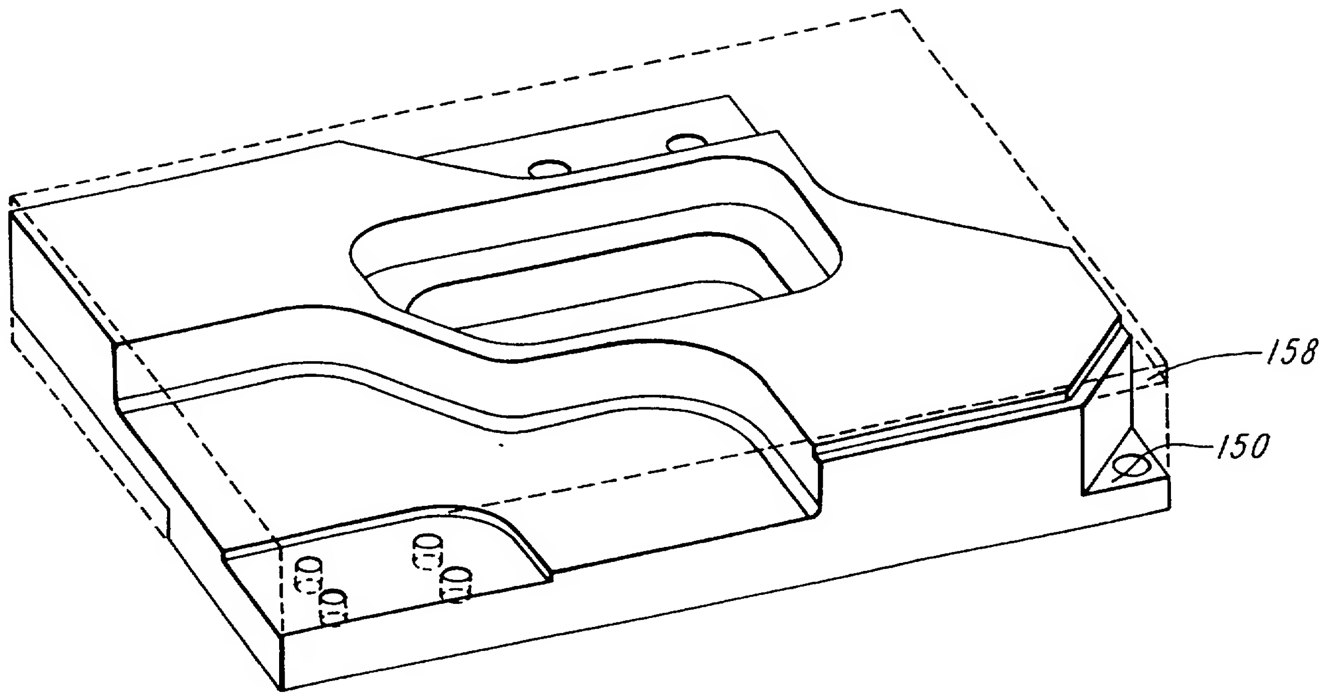


FIG.13A.

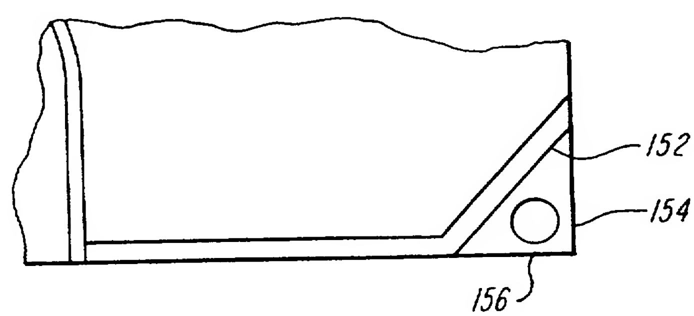


FIG.13B.

14.12.00

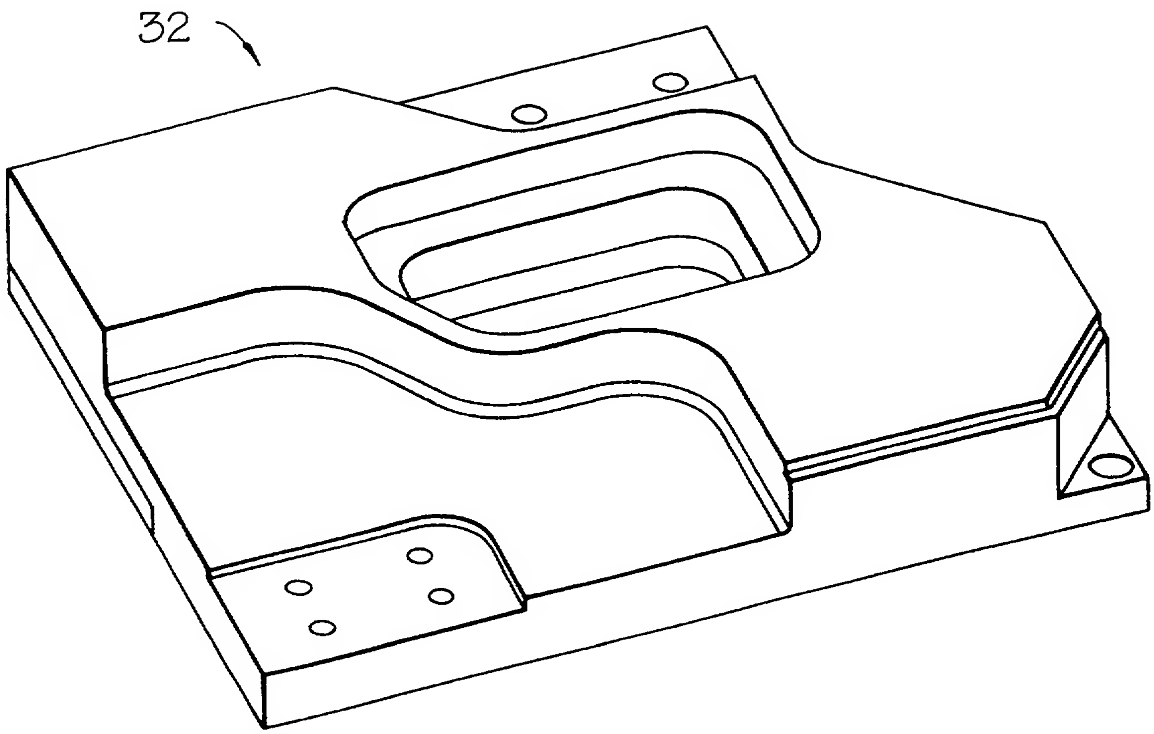


FIG.13C.

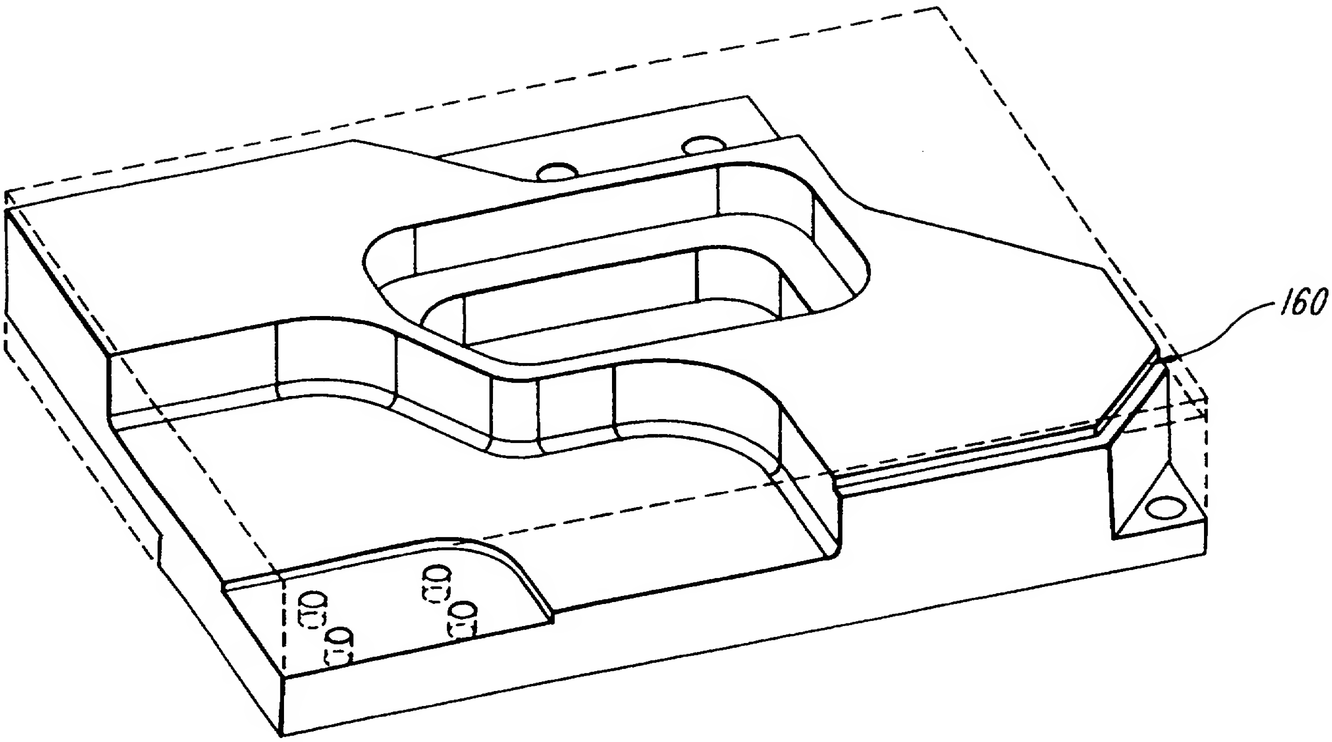


FIG.14A.

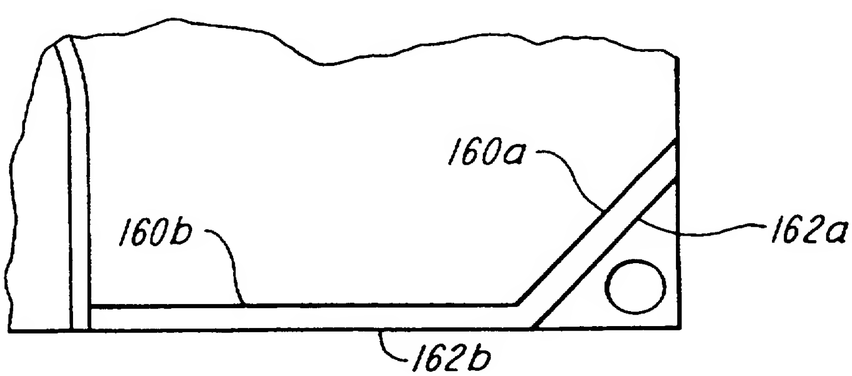


FIG.14B.

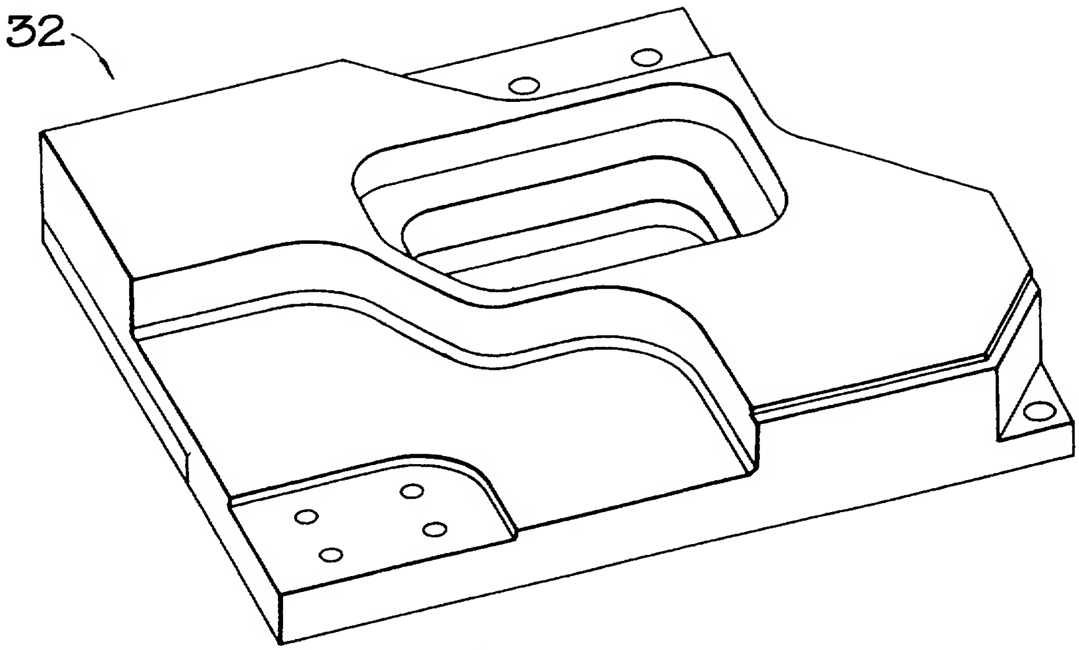


FIG.15A.

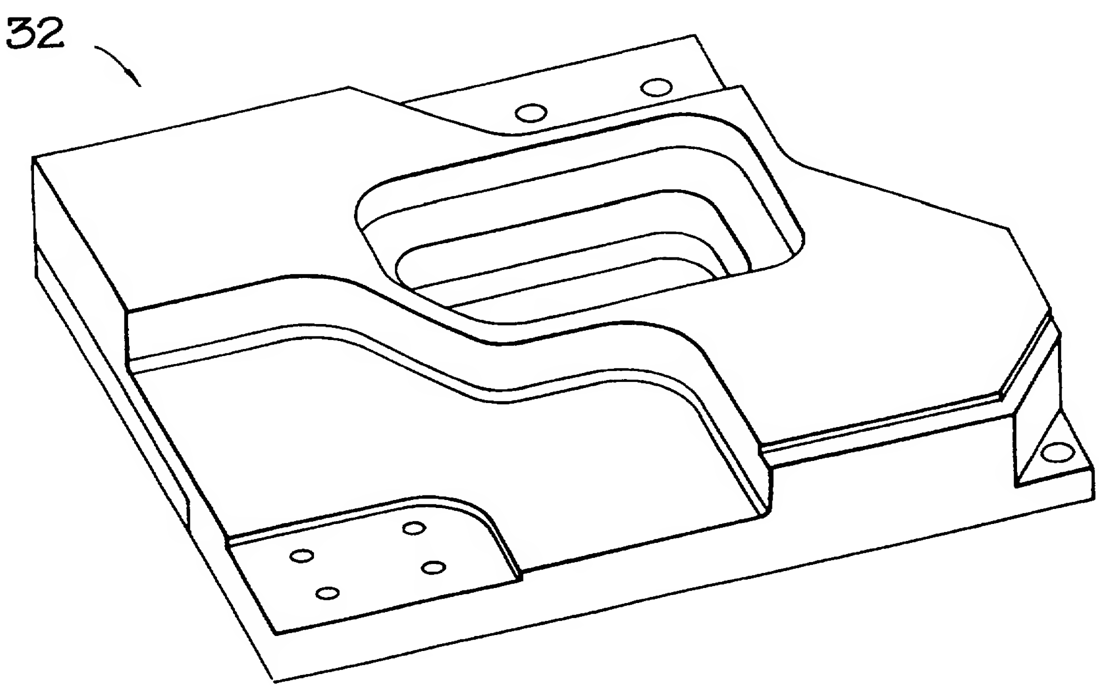


FIG.15B.

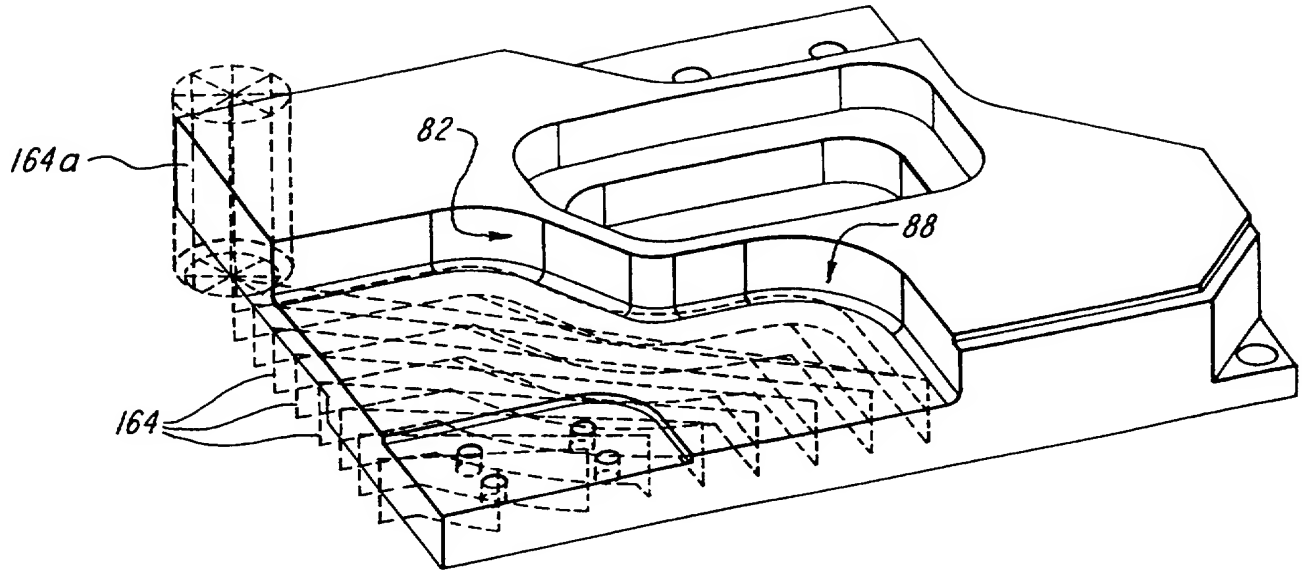


FIG.16A.

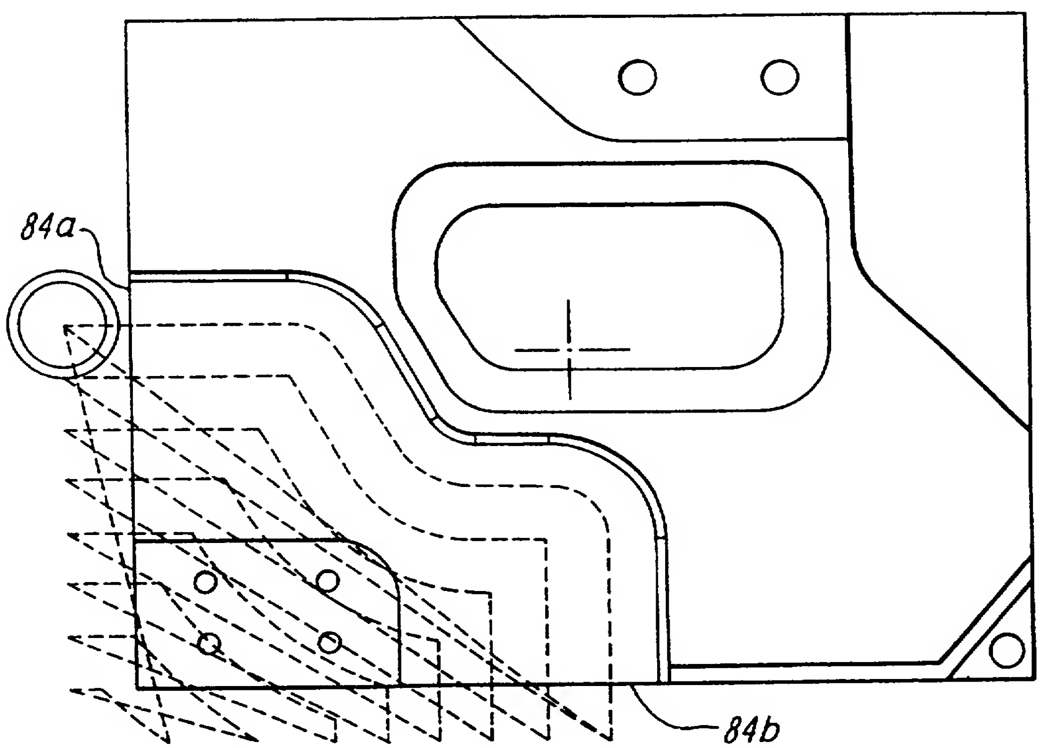


FIG.16B.

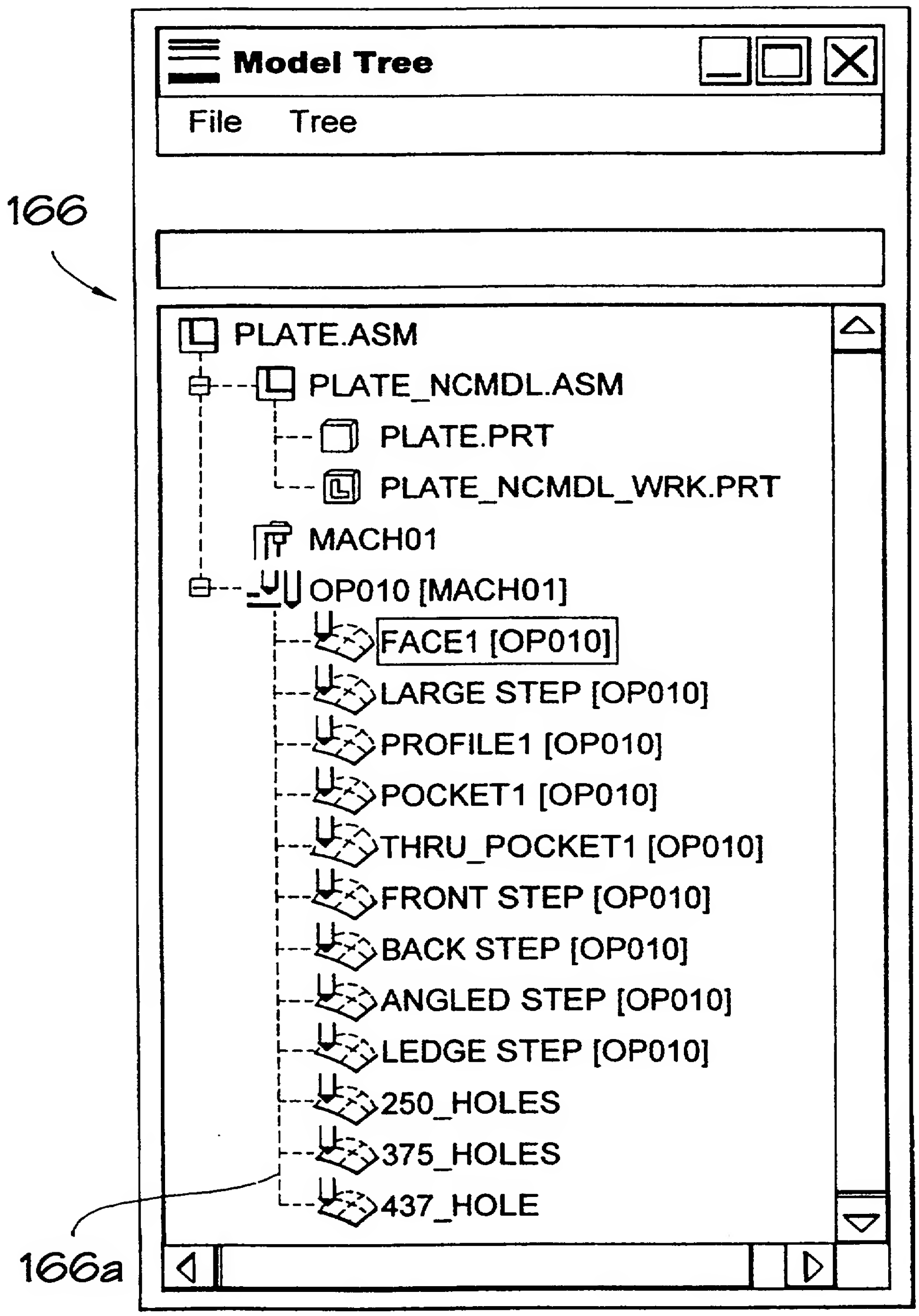

166
Model Tree
File
Tree
PLATE.ASM
PLATE_NCMDL.ASM
PLATE.PRT
PLATE_NCMDL_WRK.PRT
MACH01
OP010 [MACH01]
FACE1 [OP010]
LARGE STEP [OP010]
PROFILE1 [OP010]
POCKET1 [OP010]
THRU_POCKET1 [OP010]
FRONT STEP [OP010]
BACK STEP [OP010]
ANGLED STEP [OP010]
LEDGE STEP [OP010]
250_HOLES
375_HOLES
437_HOLE
166a

FIG.17.

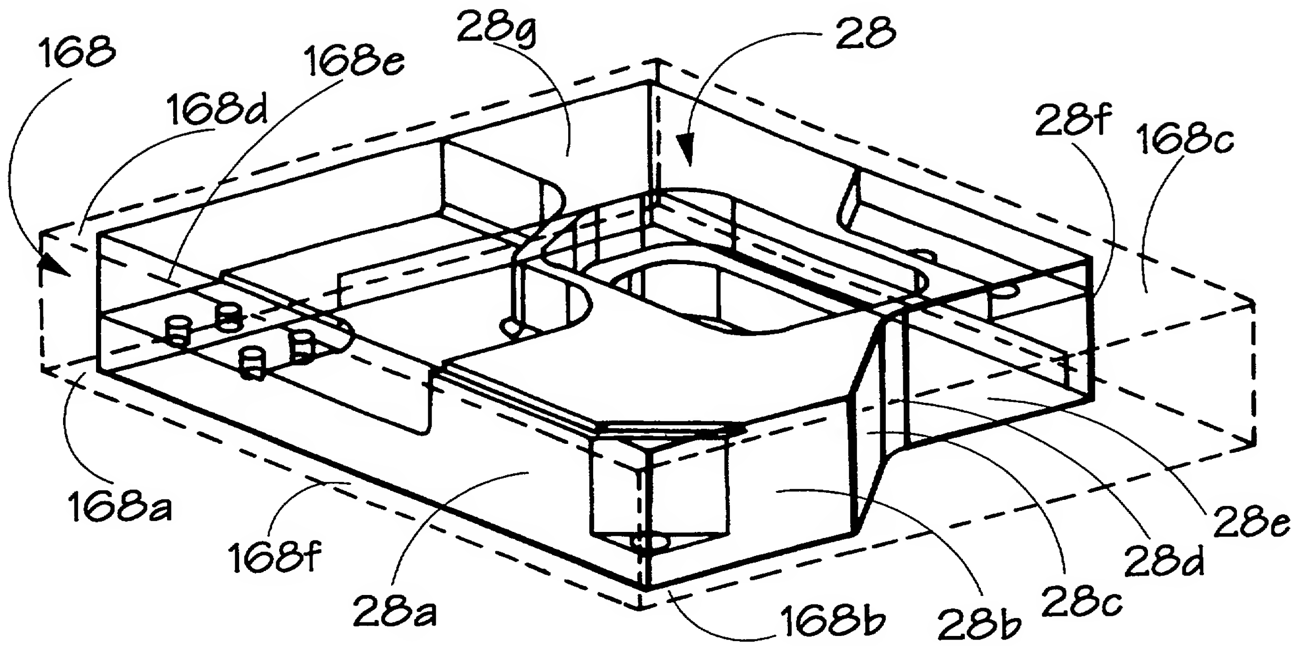


FIG.18A.

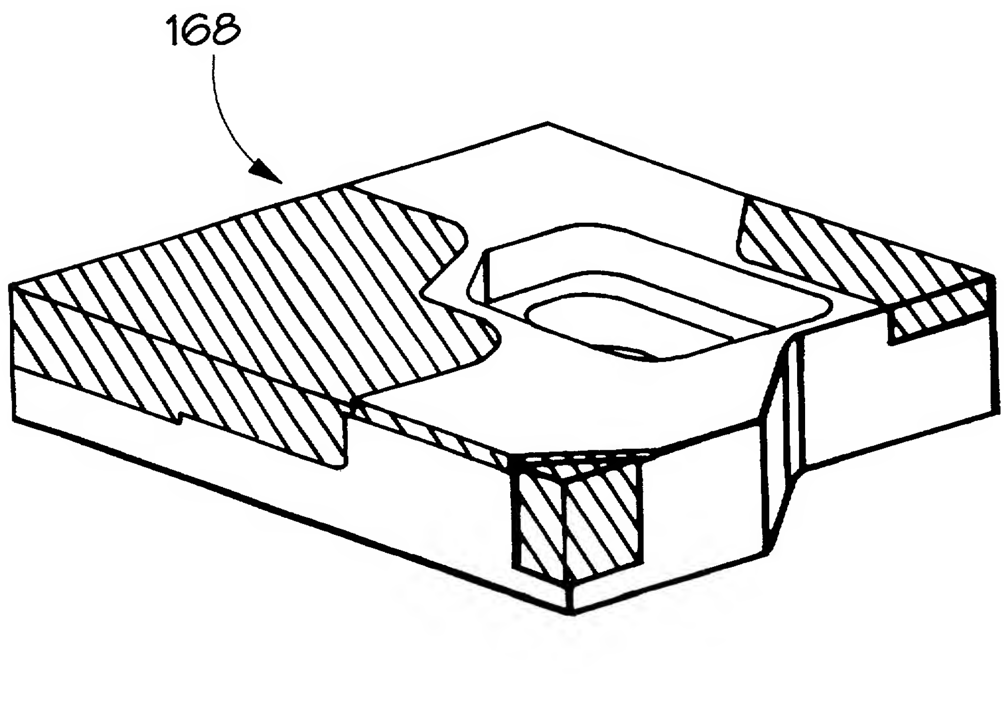


FIG.18B.

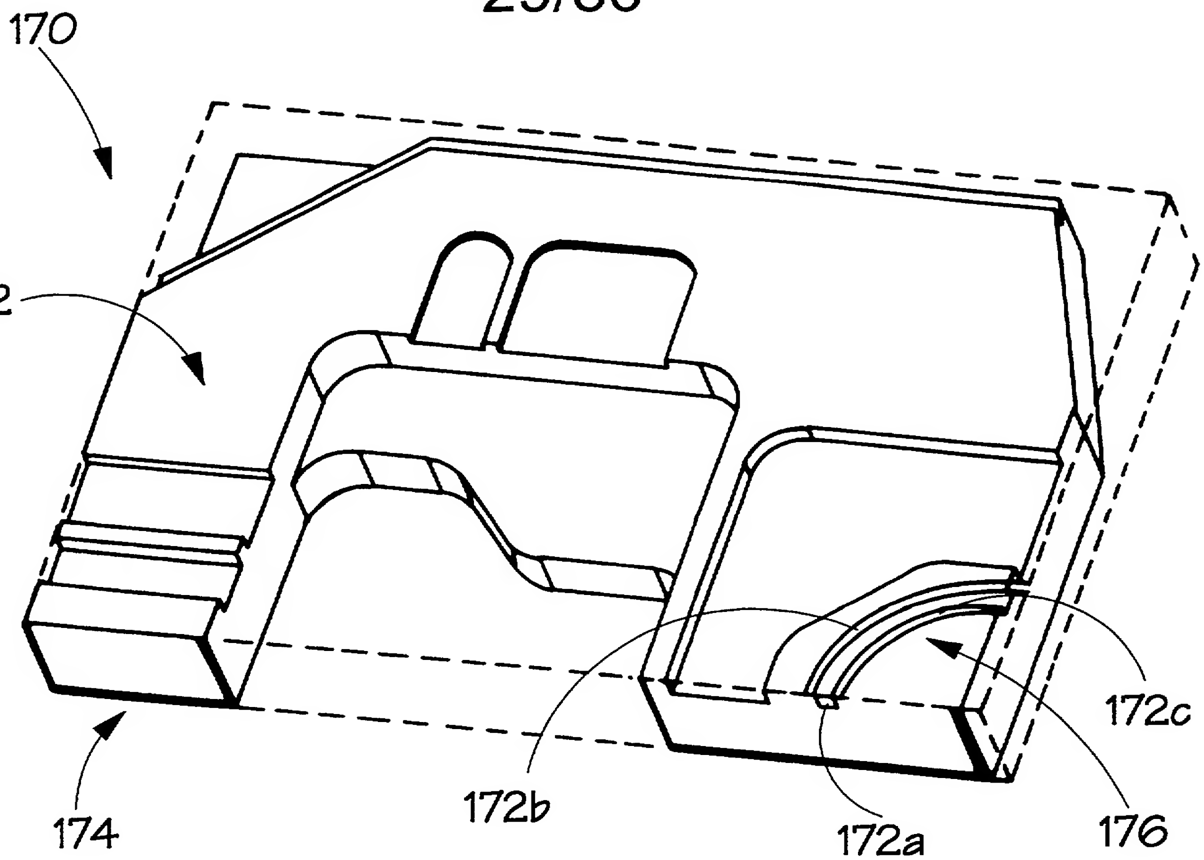


FIG.19A.

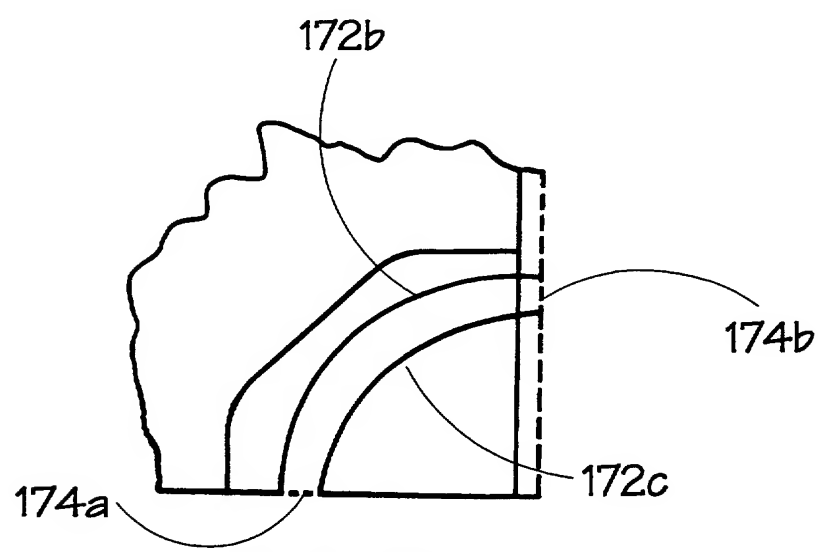


FIG.19B.

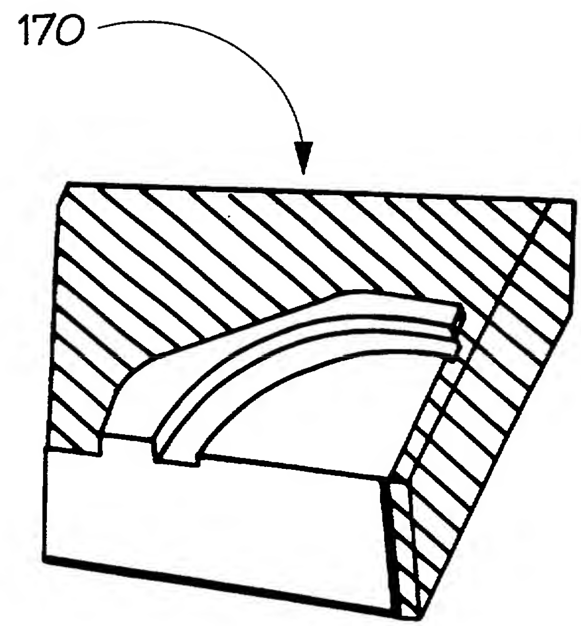


FIG.19C.

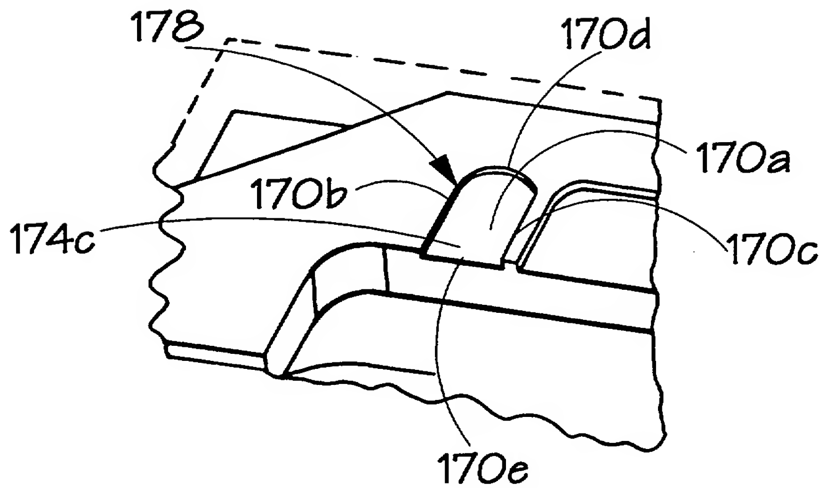


FIG.20A.

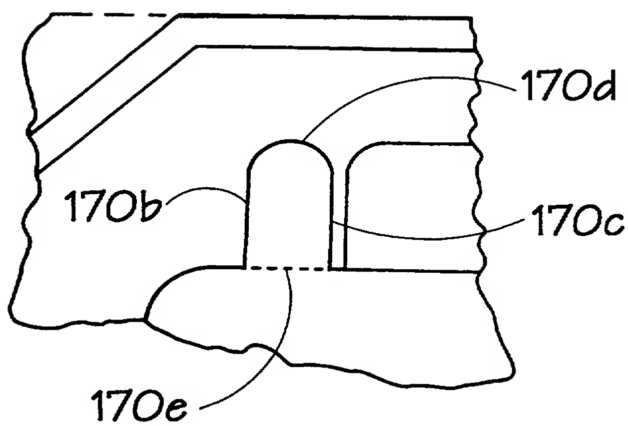


FIG.20B.

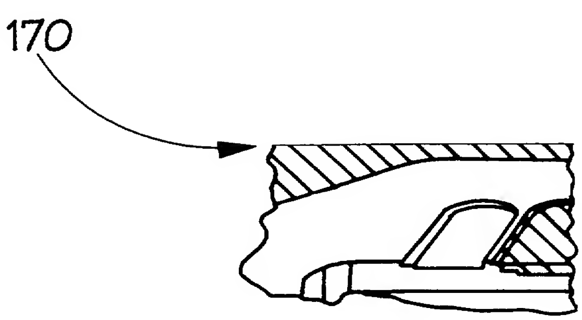


FIG.20C.

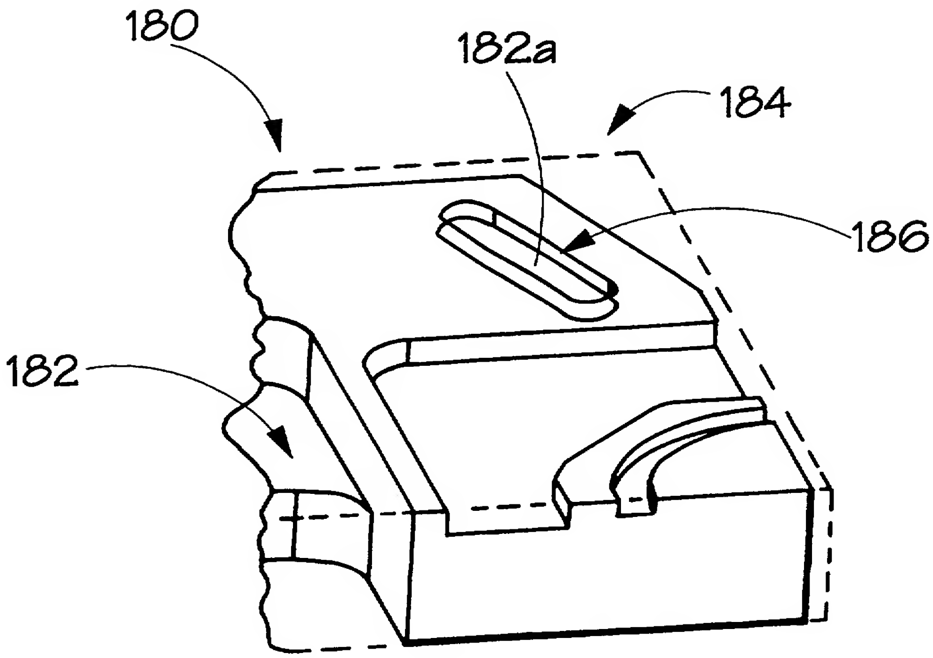


FIG.21A.

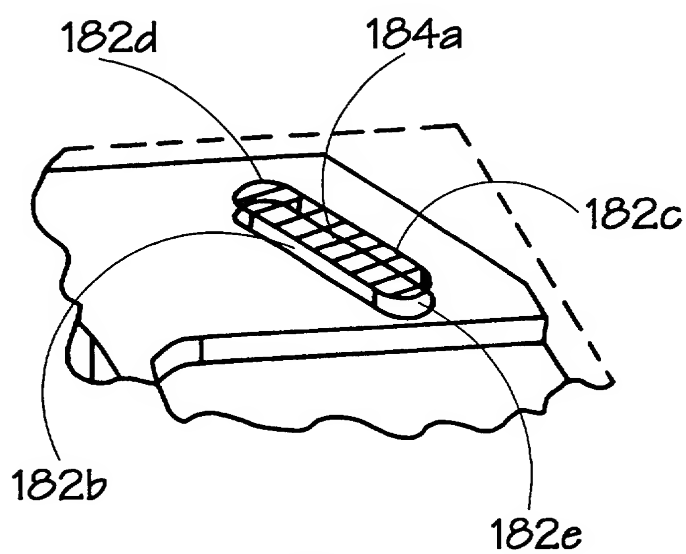


FIG.21B.

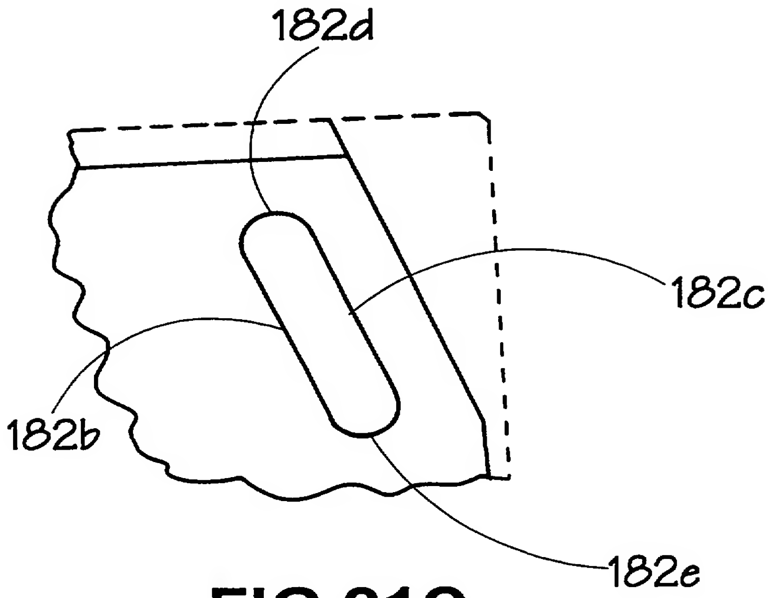


FIG.21C.

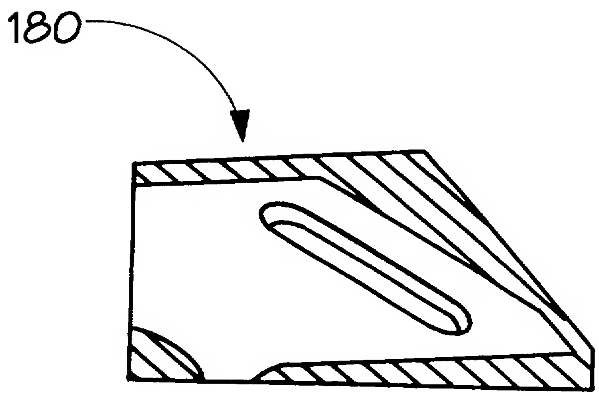


FIG.21D.

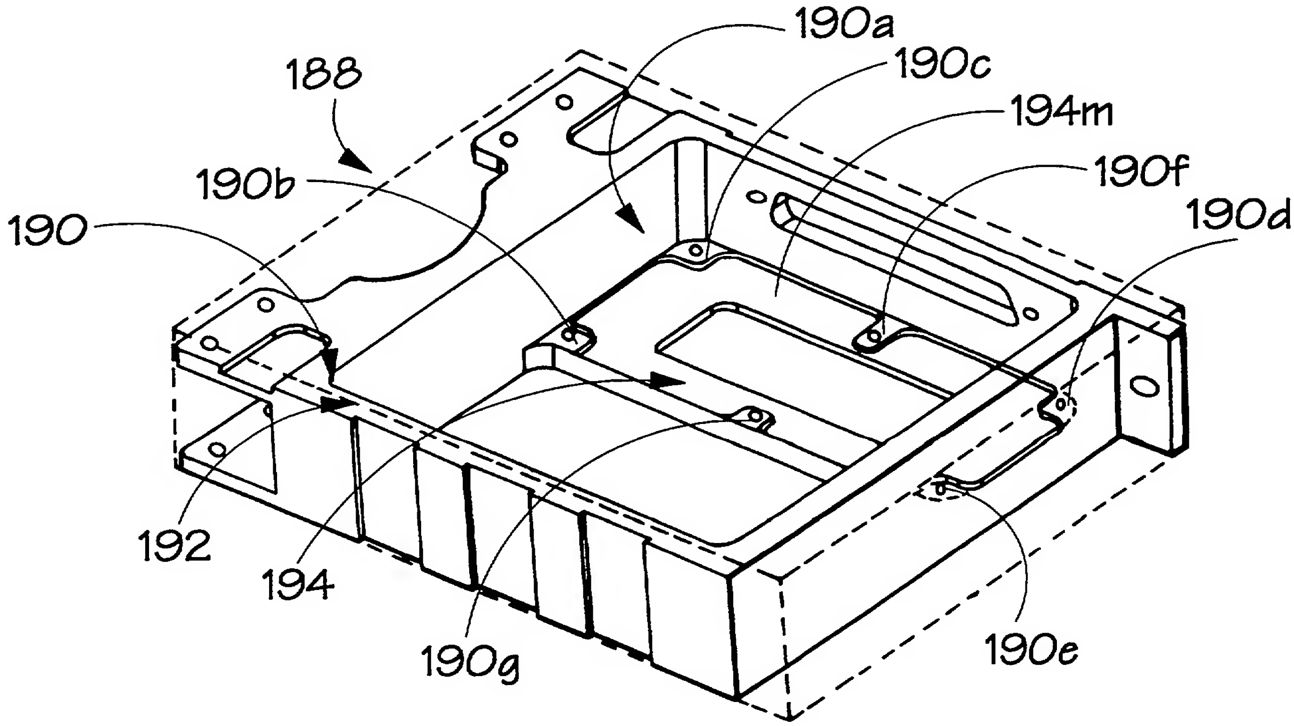


FIG.22A.

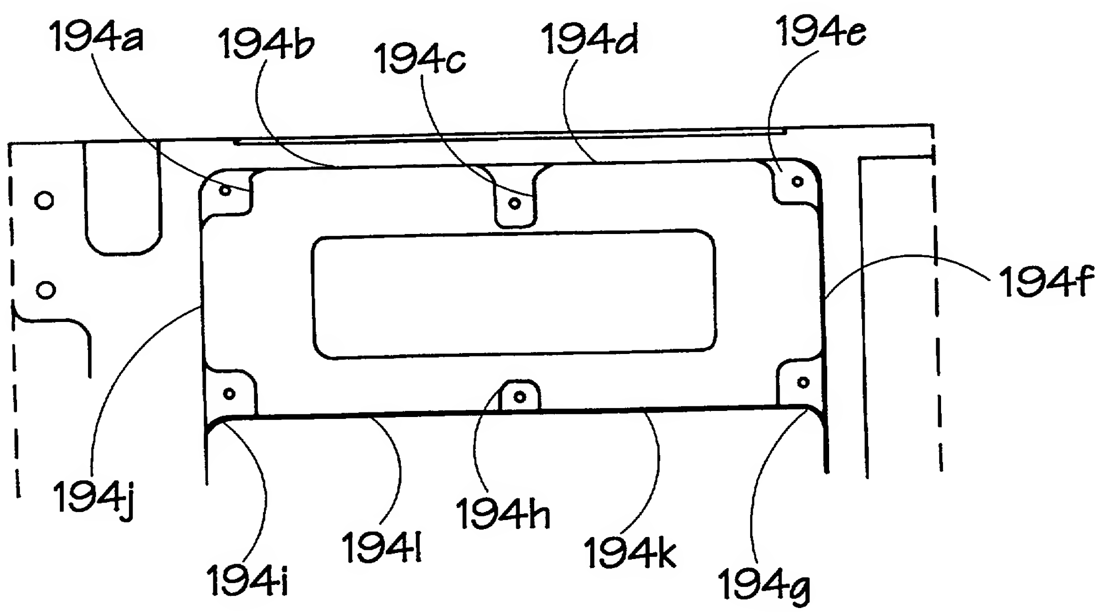


FIG.22B.

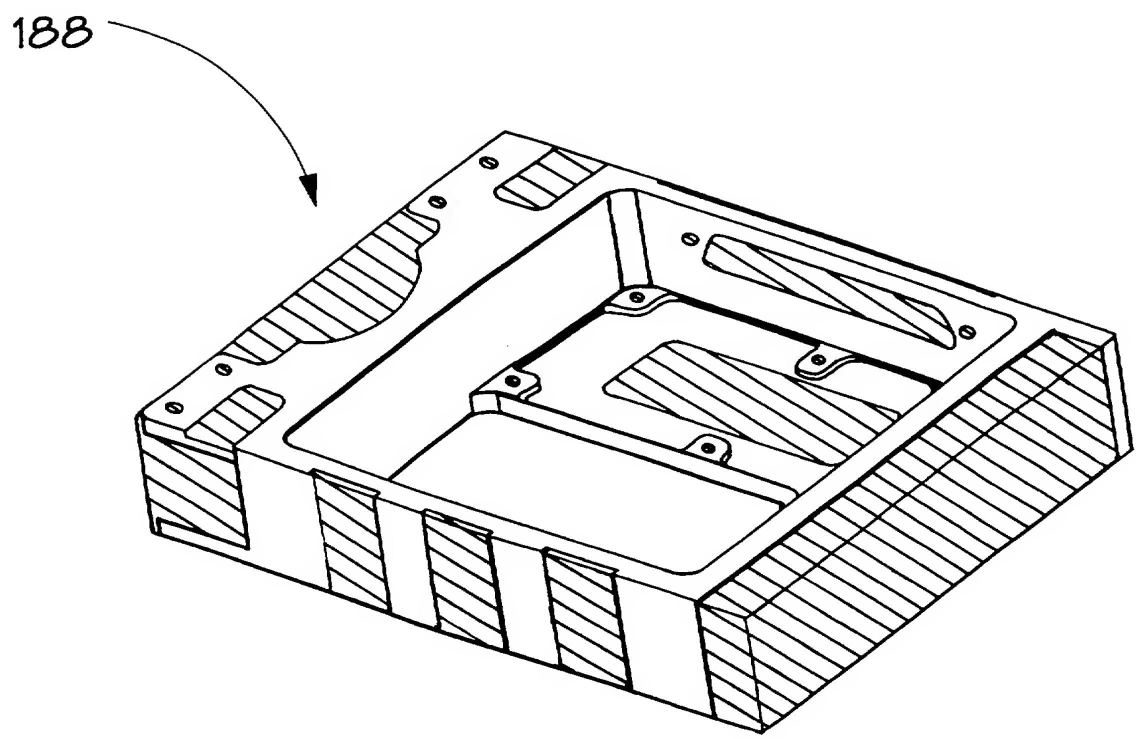


FIG.22C.

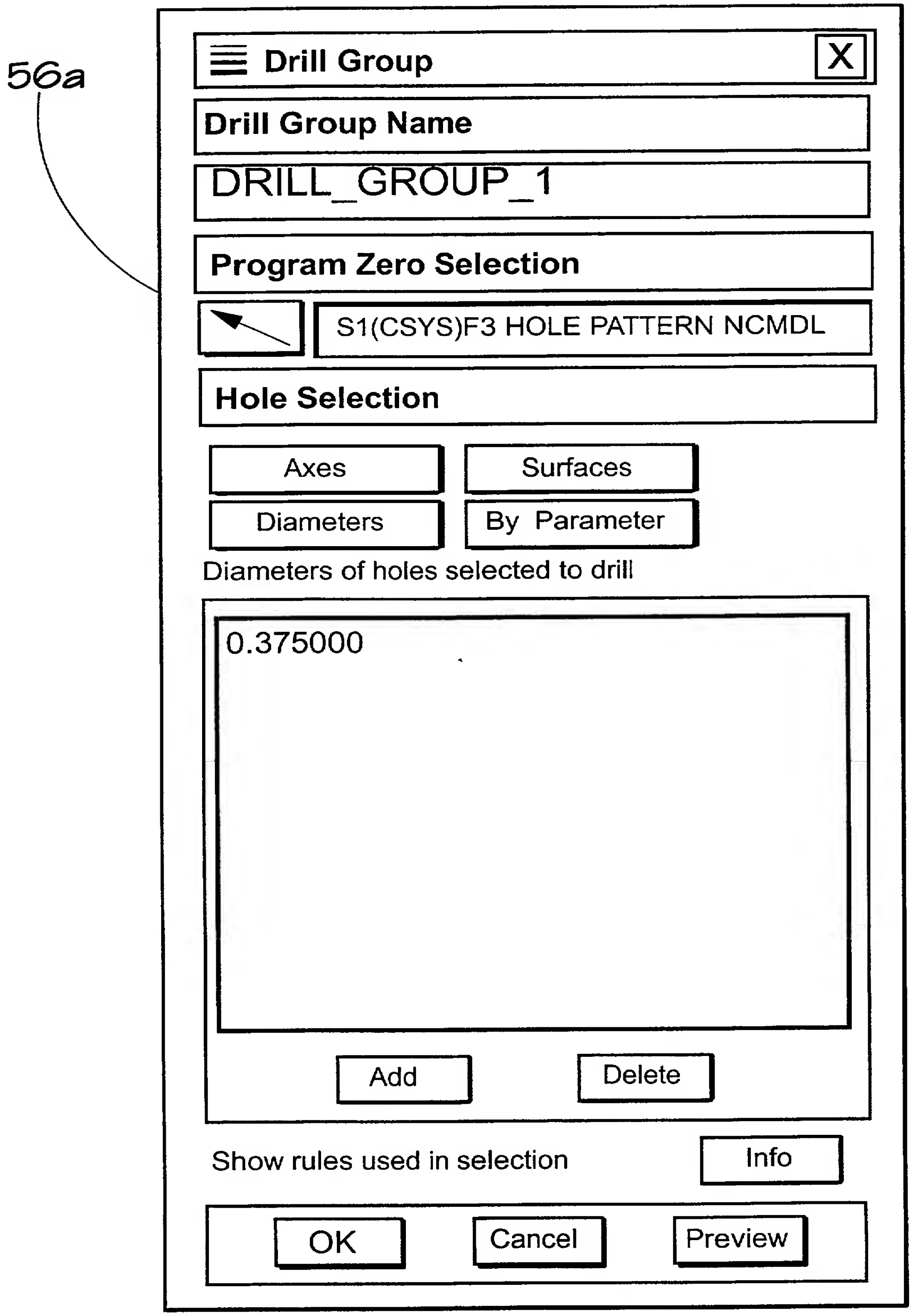

56a
Drill Group
X
Drill Group Name
DRILL_GROUP_1
Program Zero Selection
S1(CSYS)F3 HOLE PATTERN NCMDL
Hole Selection
Axes
Surfaces
Diameters
By Parameter
Diameters of holes selected to drill
0.375000
Add
Delete
Show rules used in selection
Info
OK
Cancel
Preview

FIG.23.

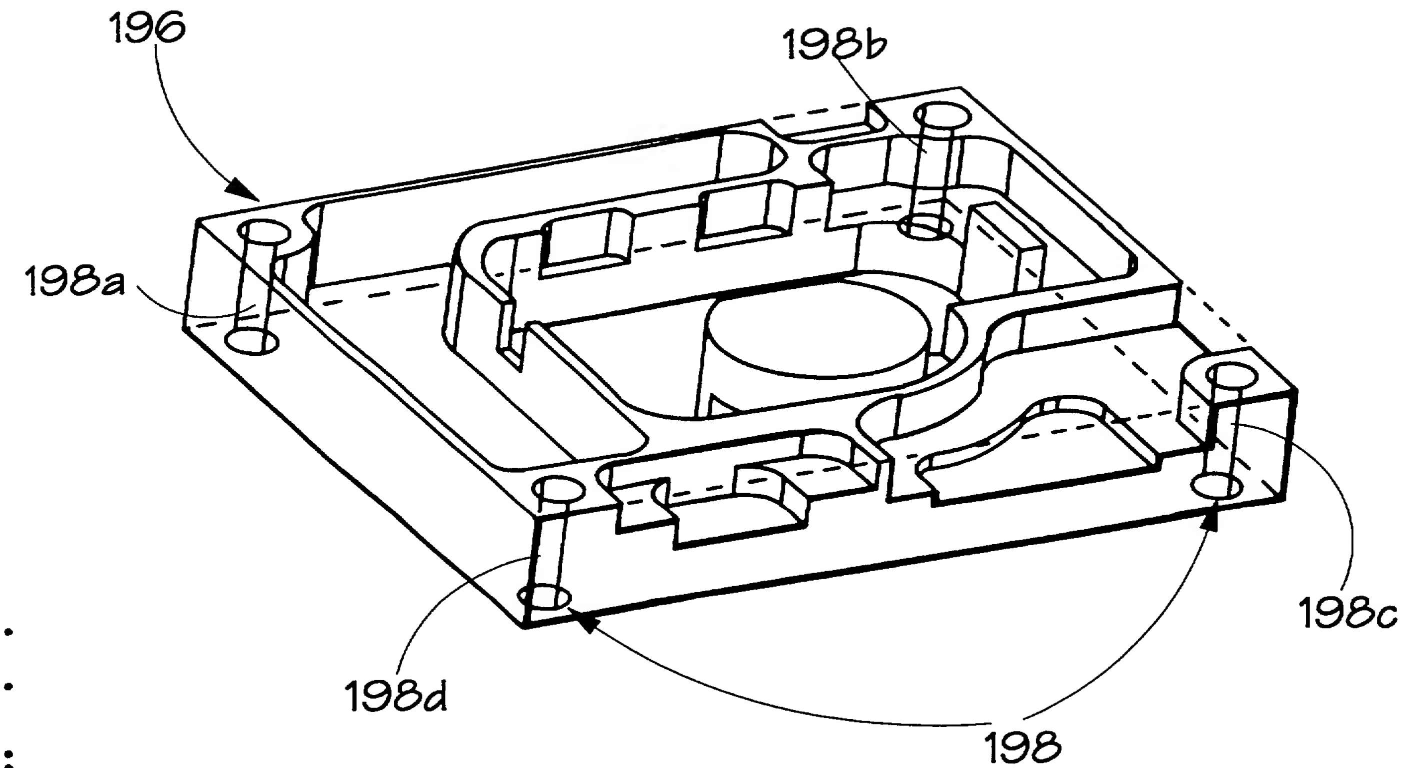


FIG.24A.

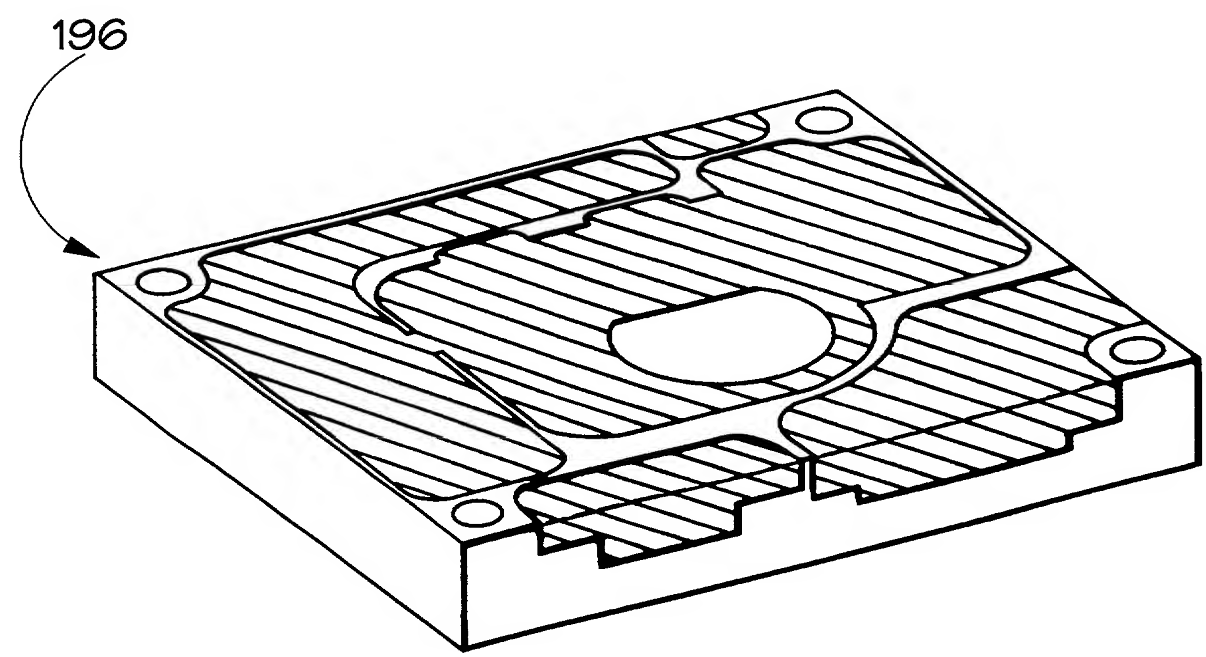


FIG.24B.

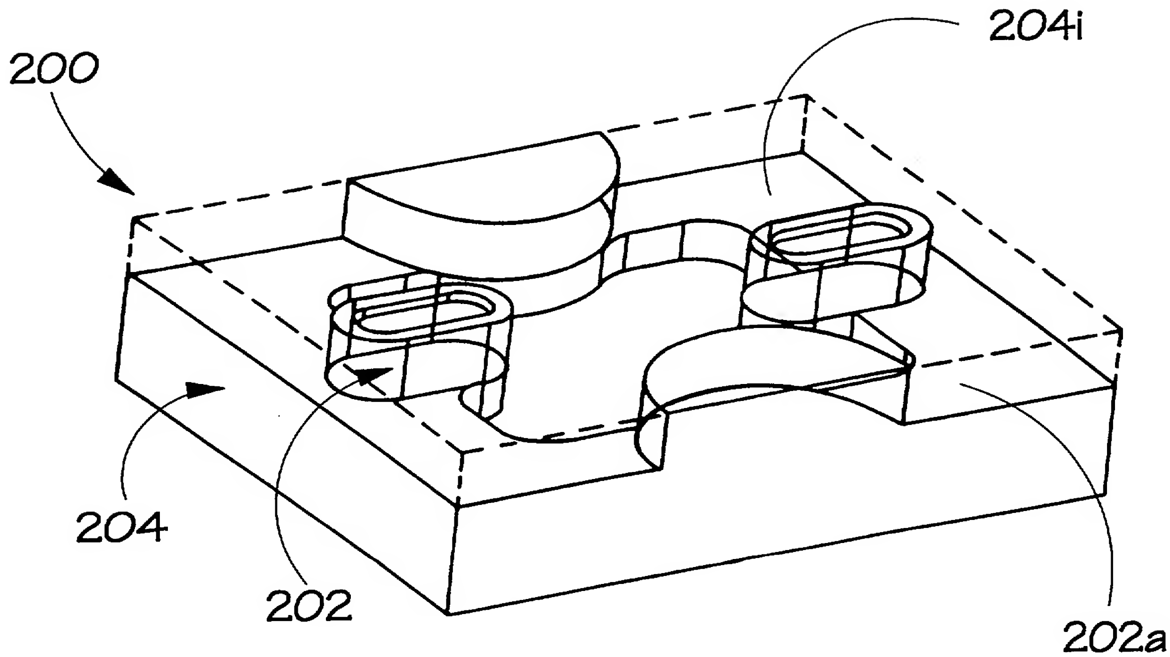


FIG.25A.

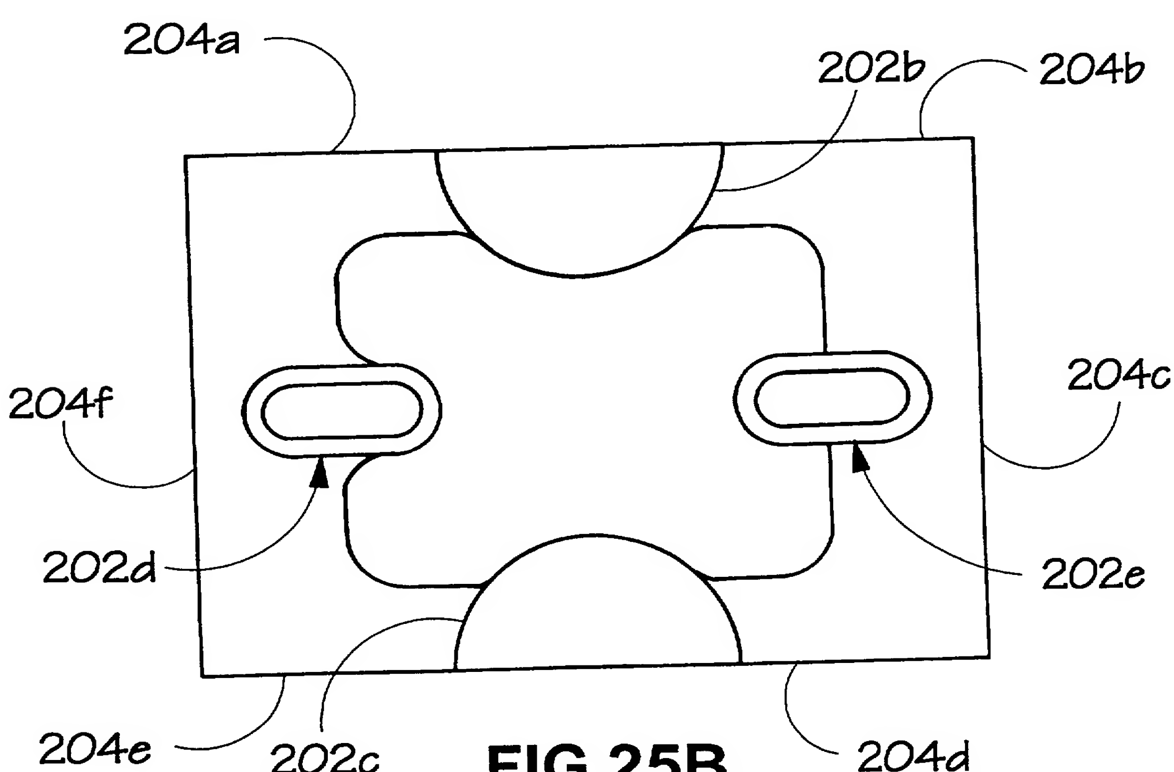


FIG.25B.

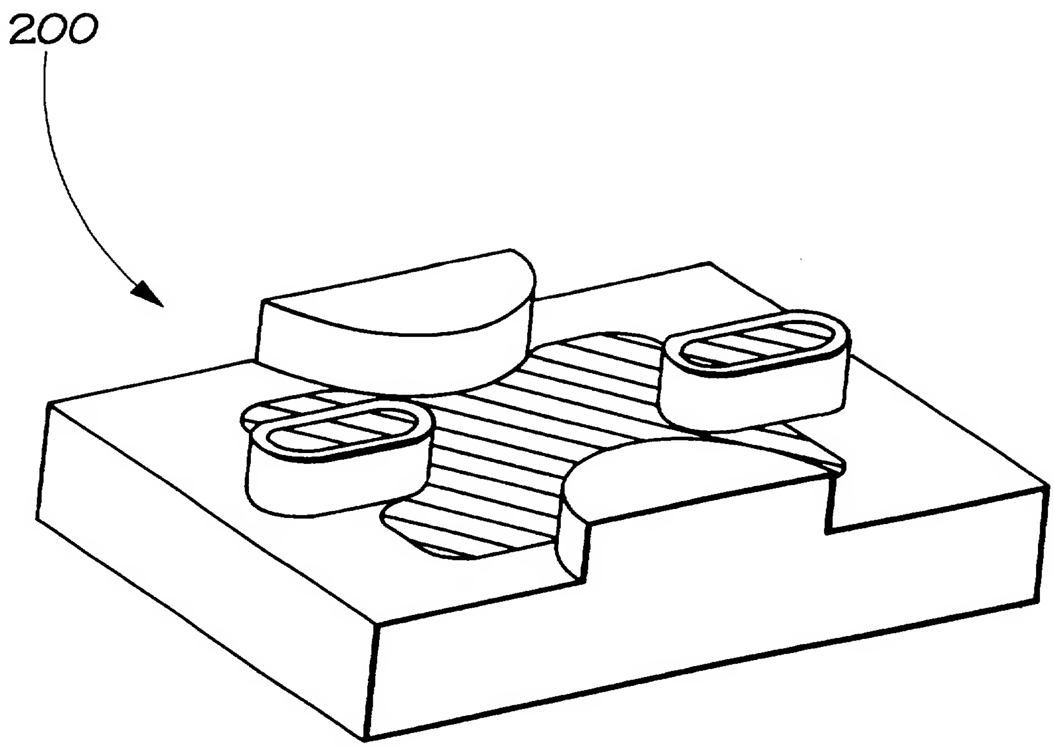


FIG.25C.

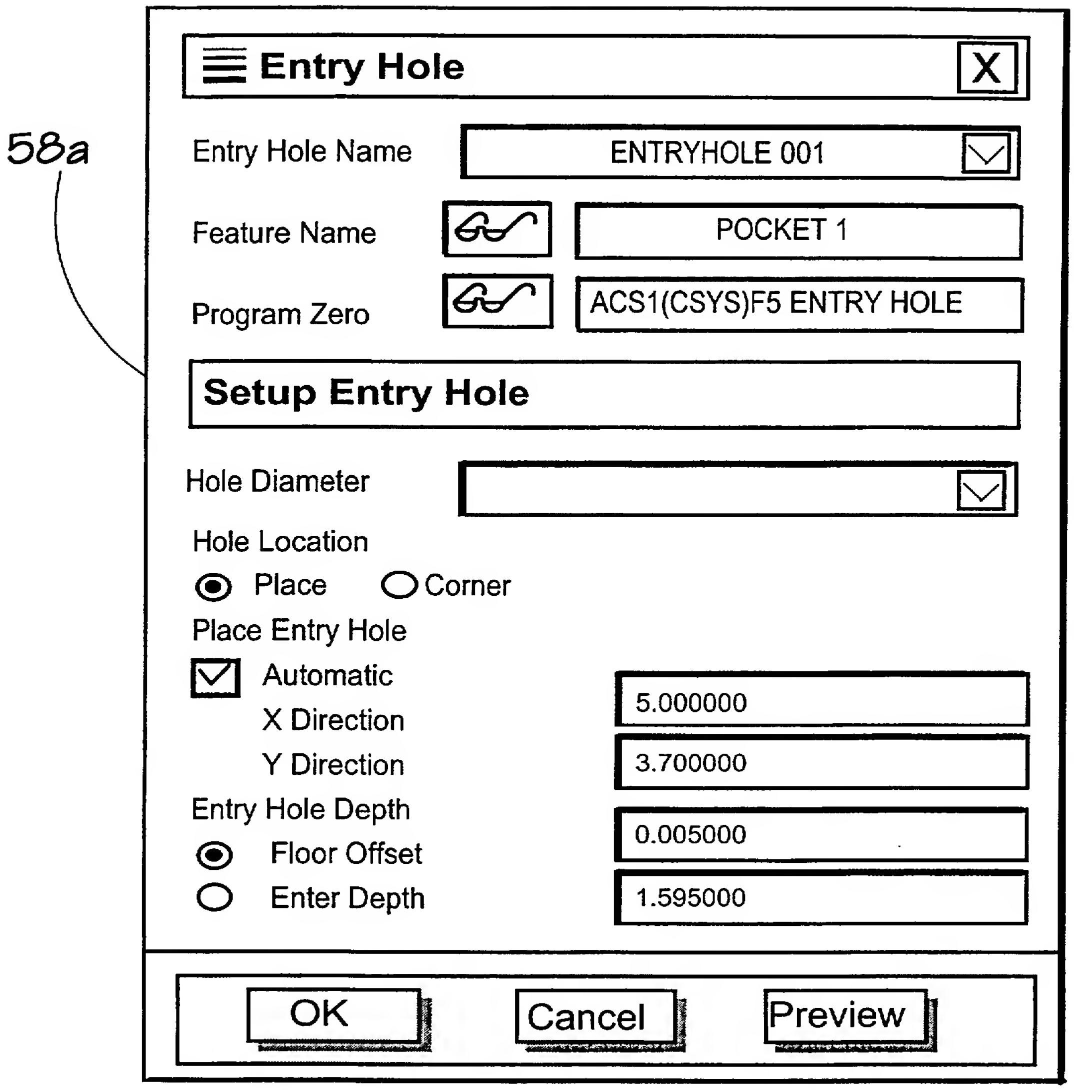


FIG.26A.

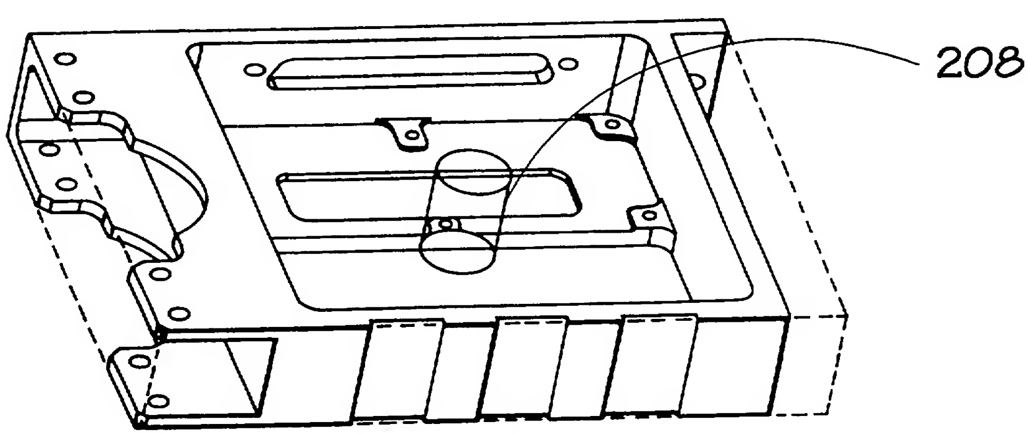


FIG.26B.

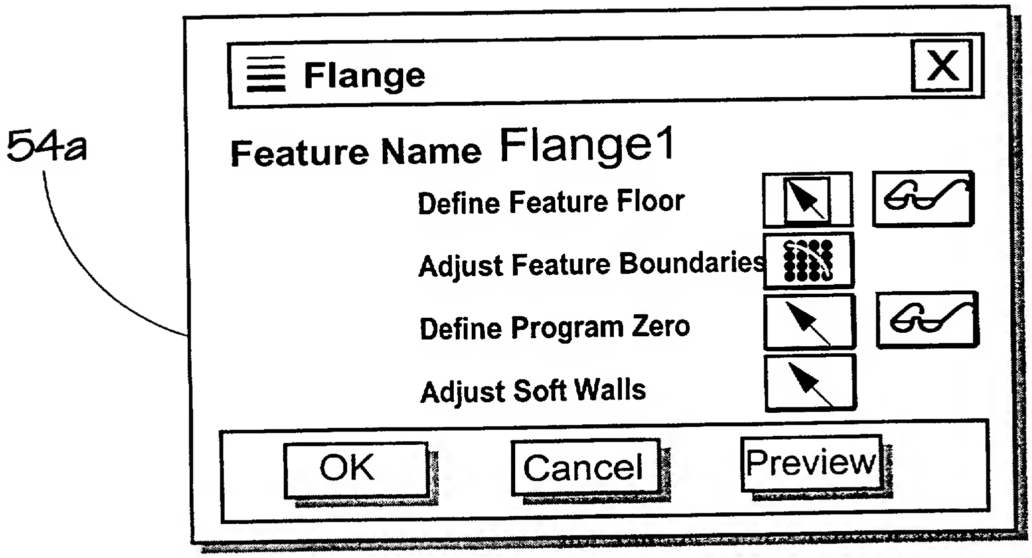


FIG.27A.

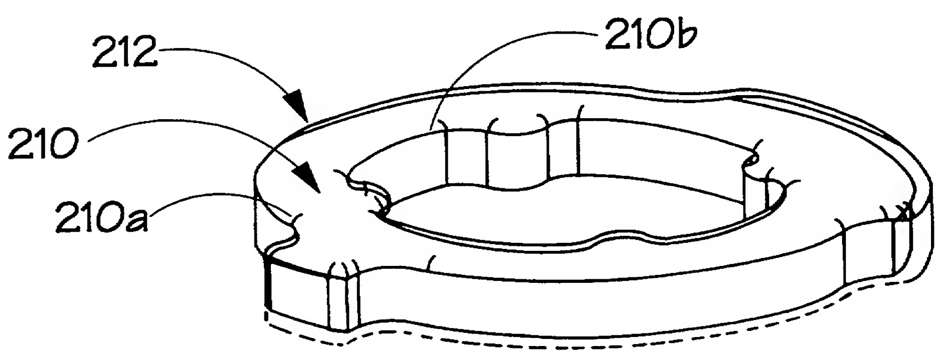


FIG.27B.

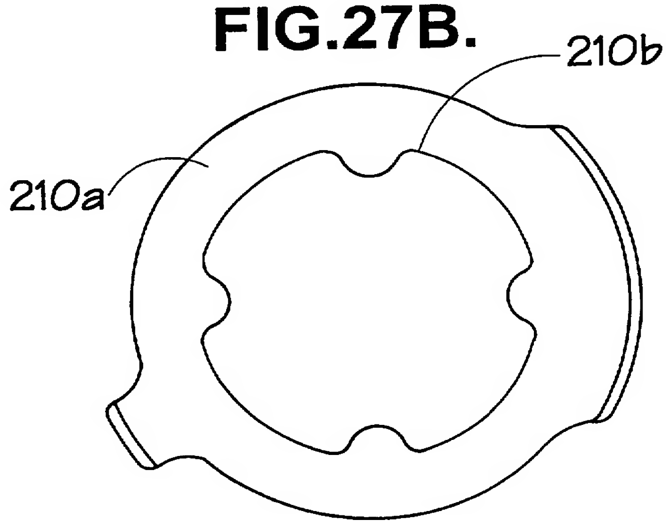


FIG.27C.

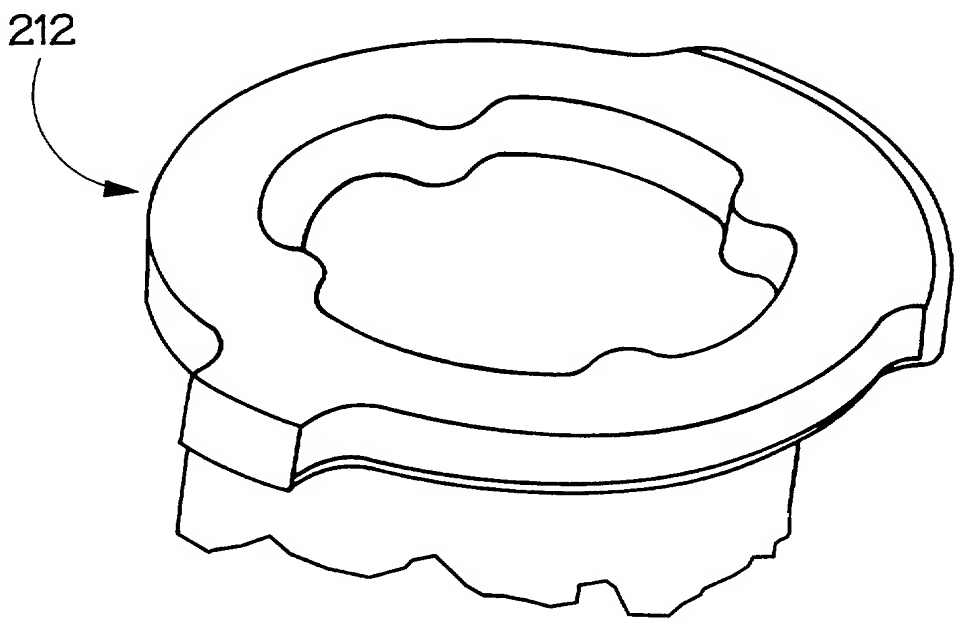


FIG.27D.

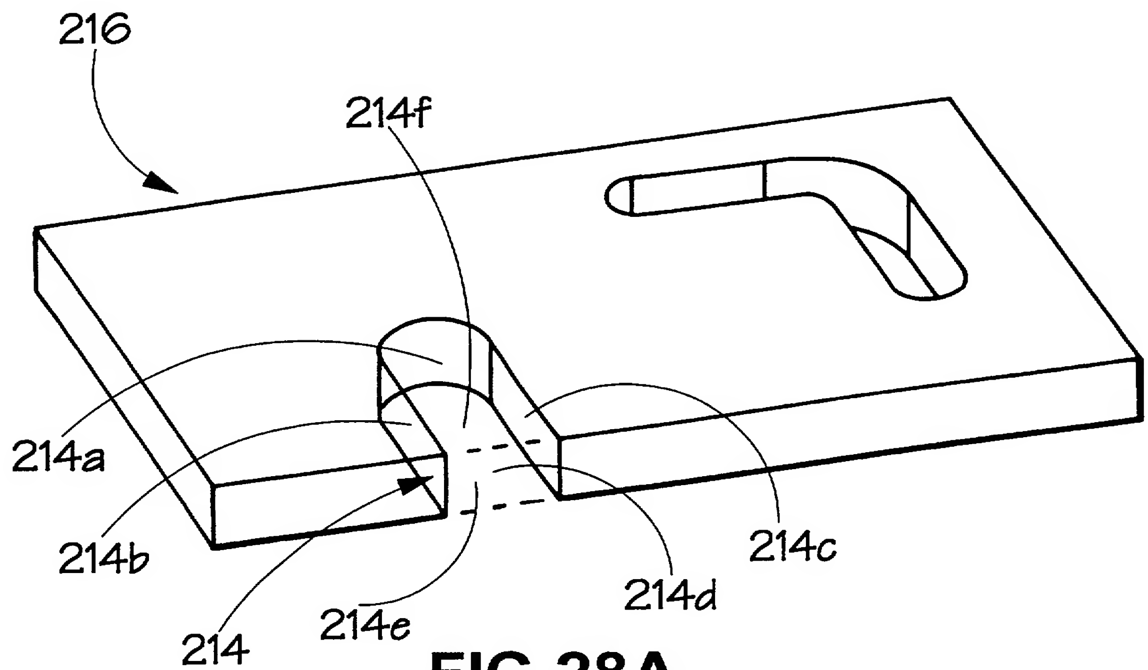


FIG.28A.

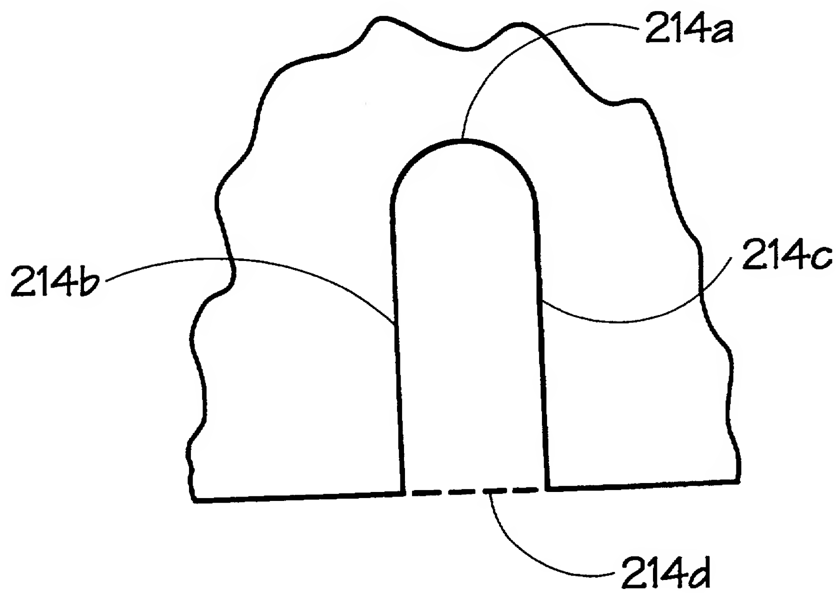


FIG.28B.

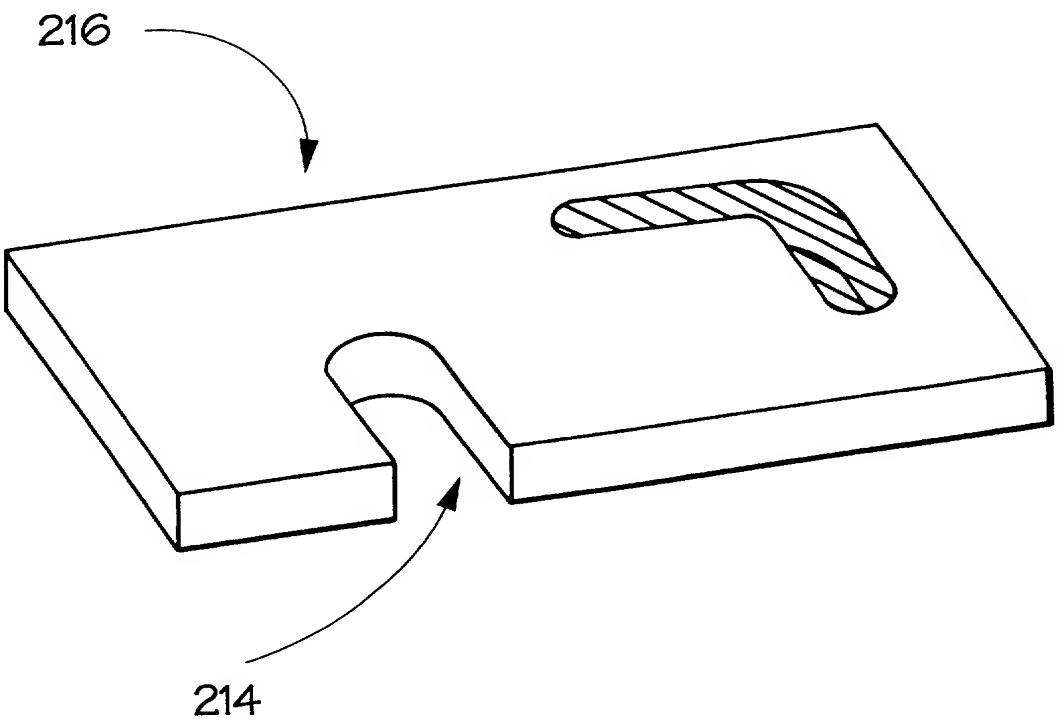


FIG.29.

14.12.00

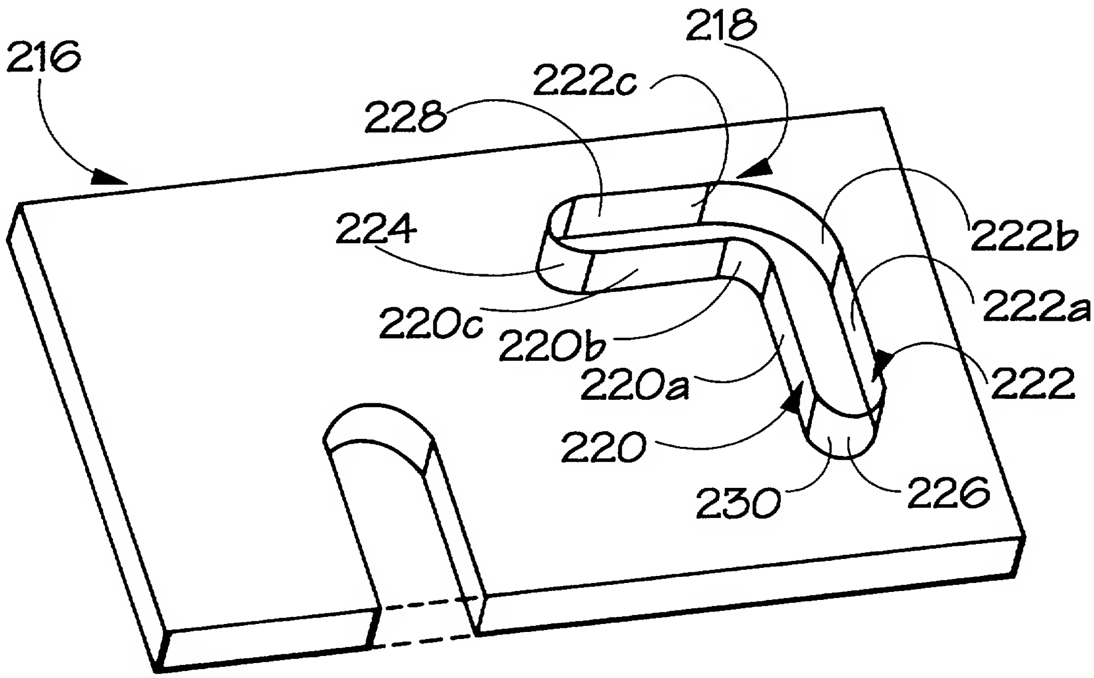


FIG.30A.

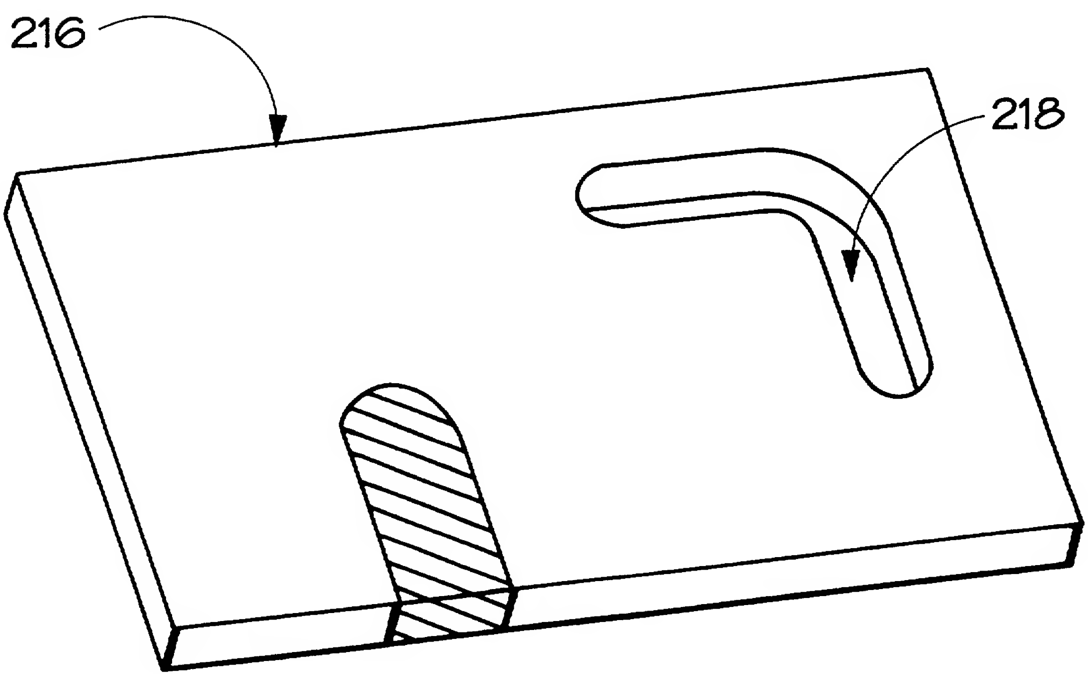


FIG.30B.

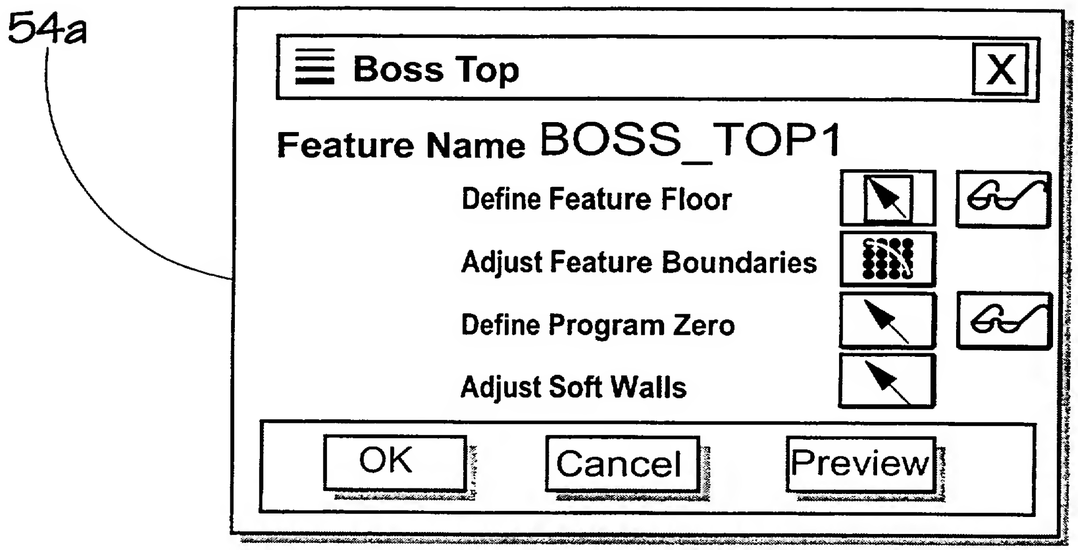


FIG.31A.

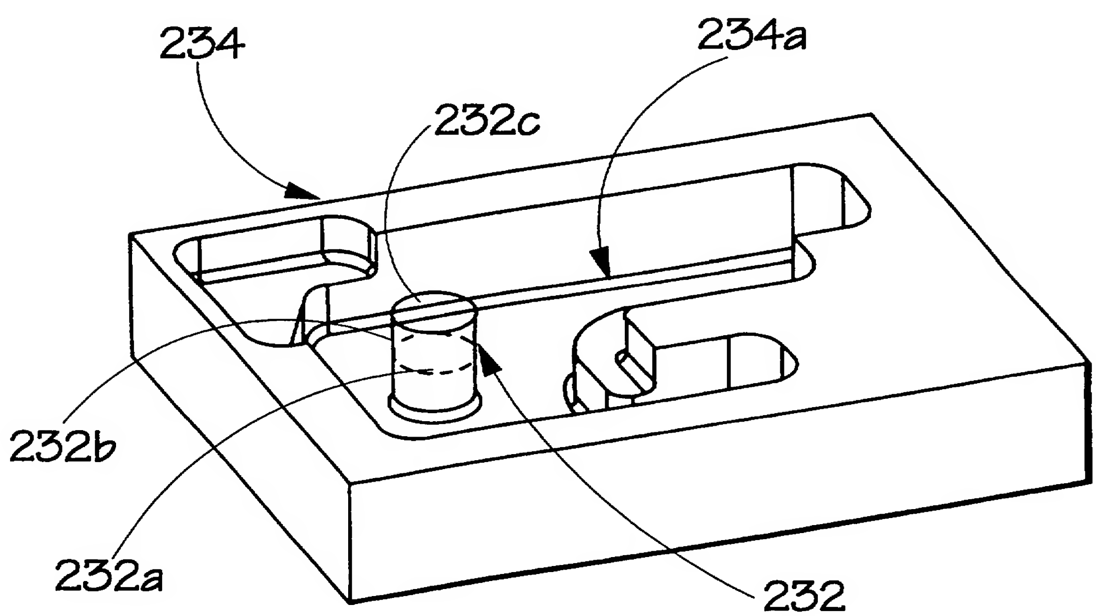


FIG.31B.

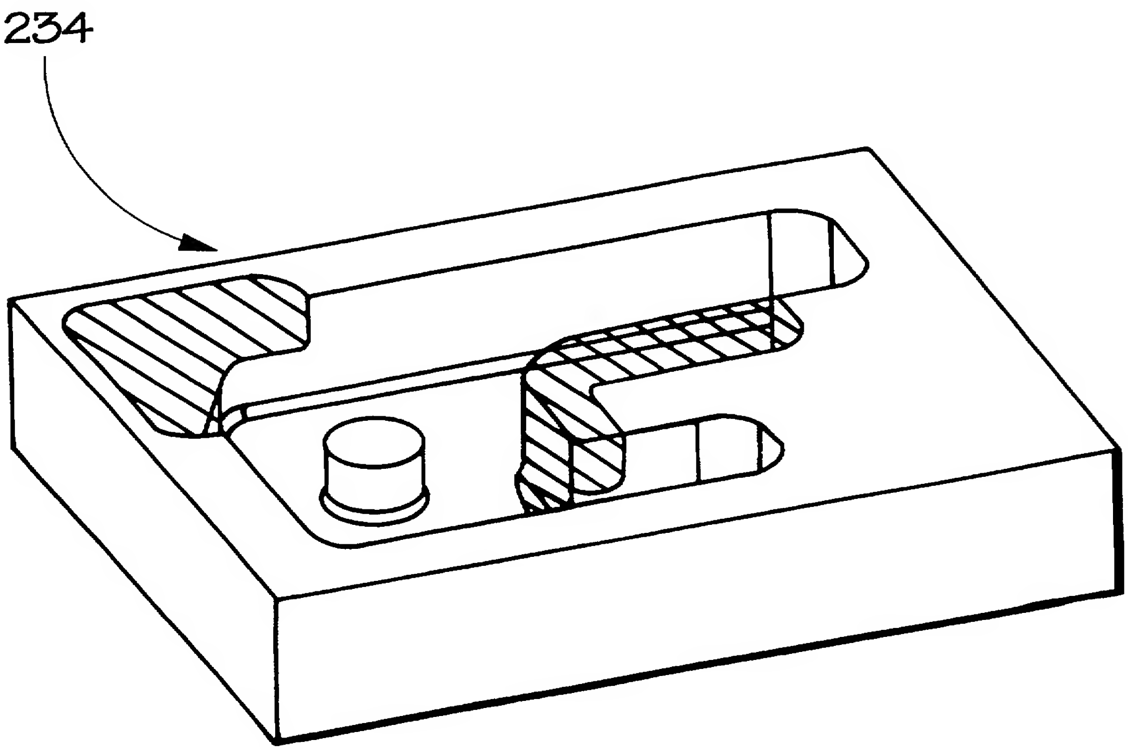


FIG.31C.

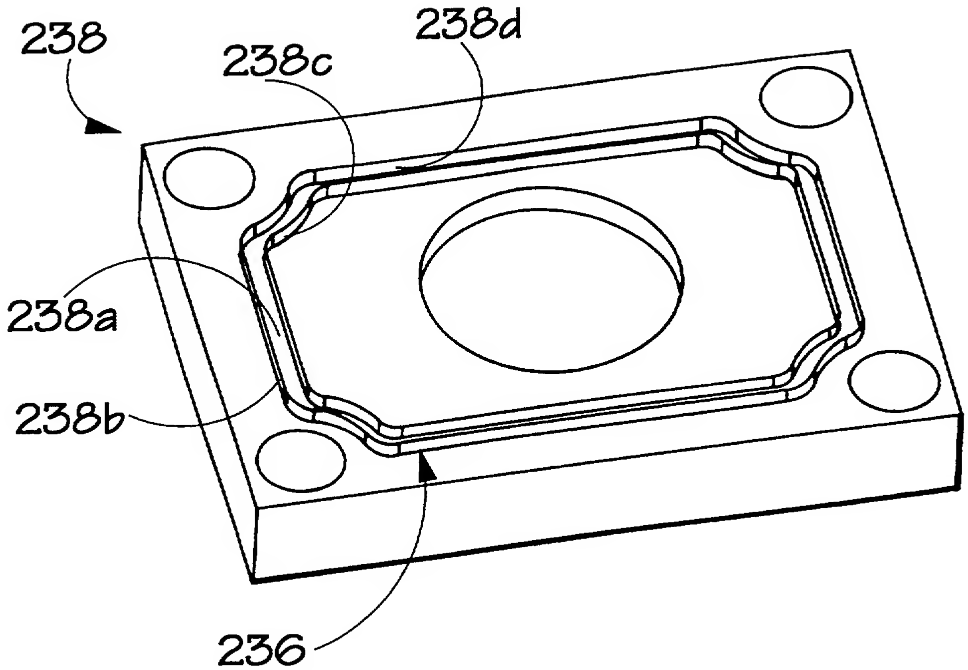


FIG.32A.

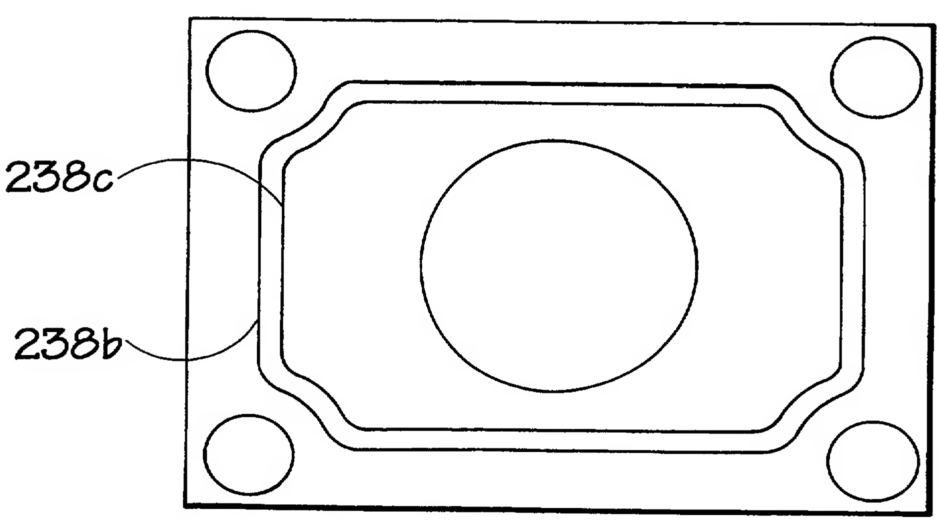


FIG.32B.

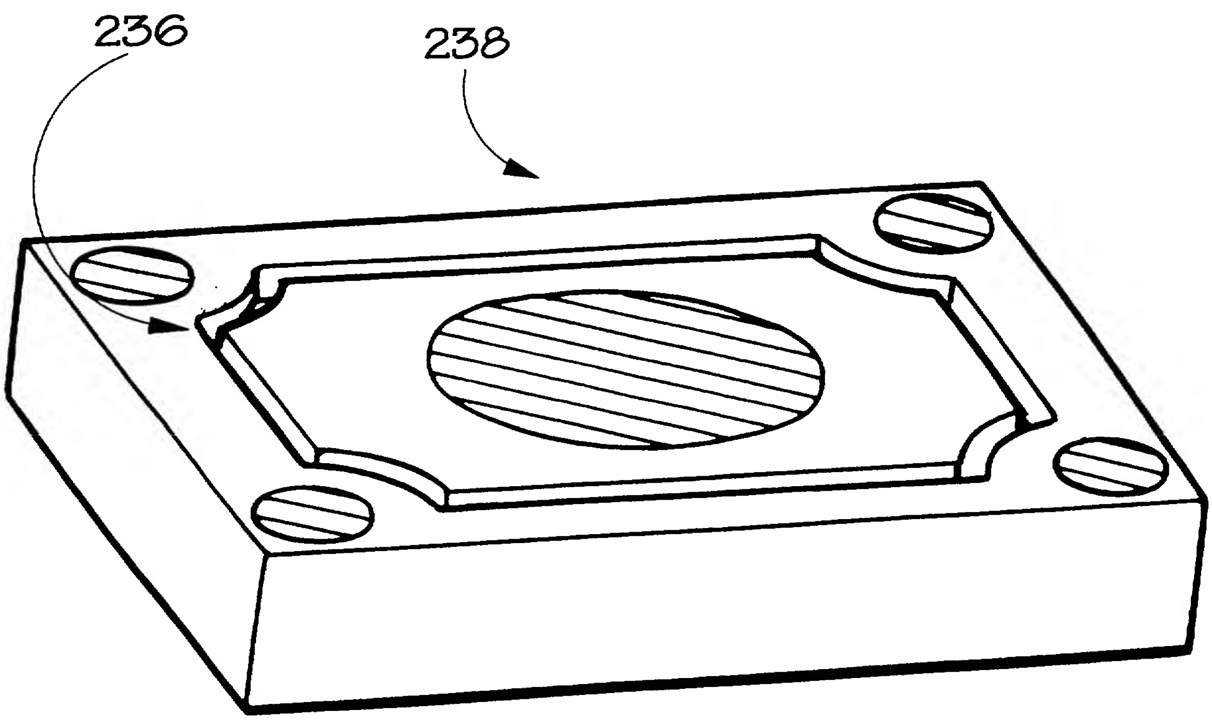


FIG.32C.

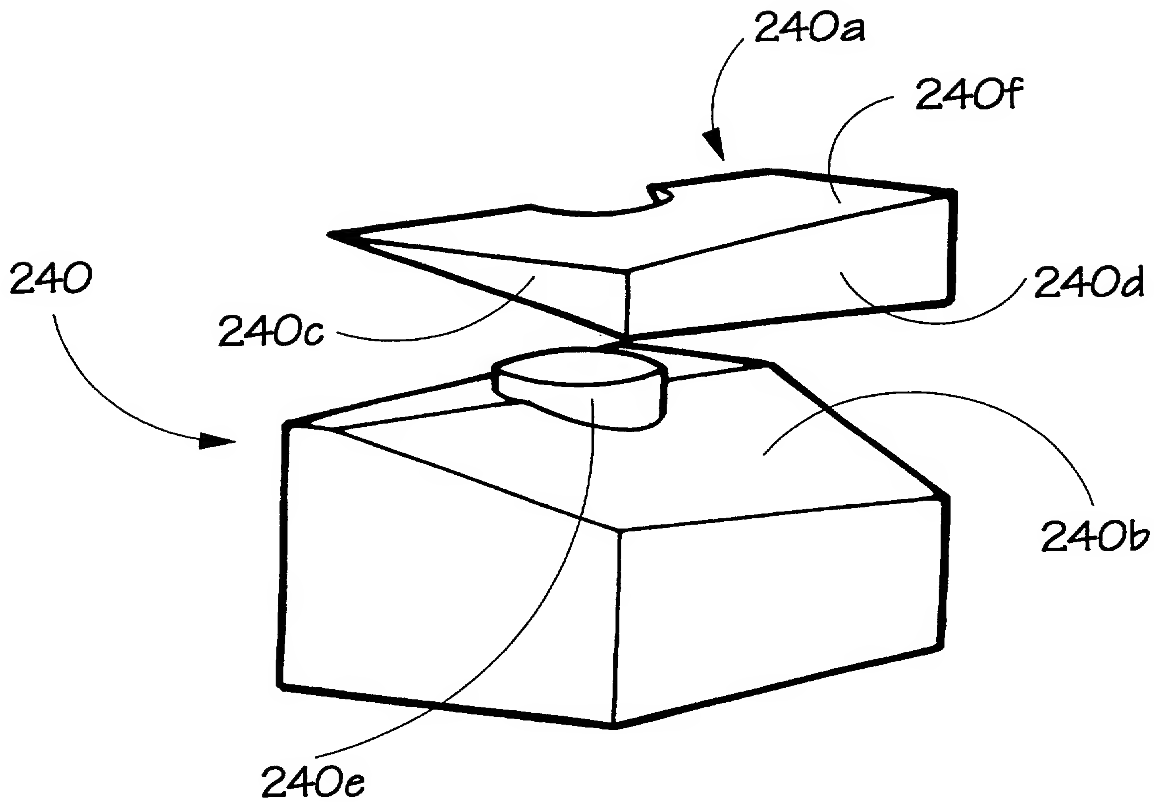


FIG.33.

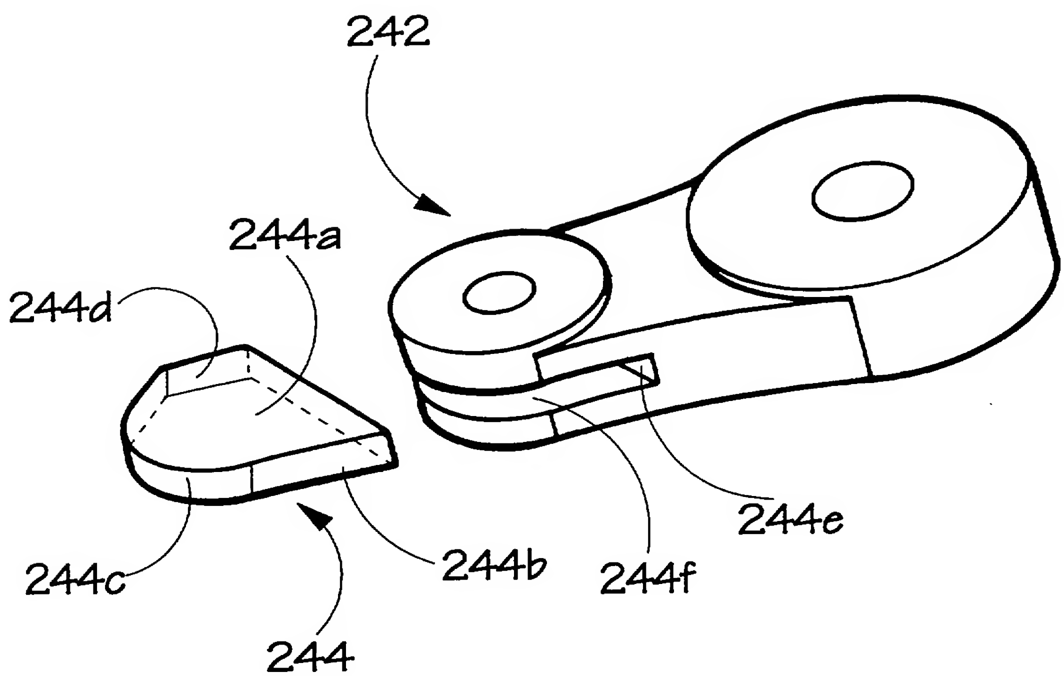


FIG.34.

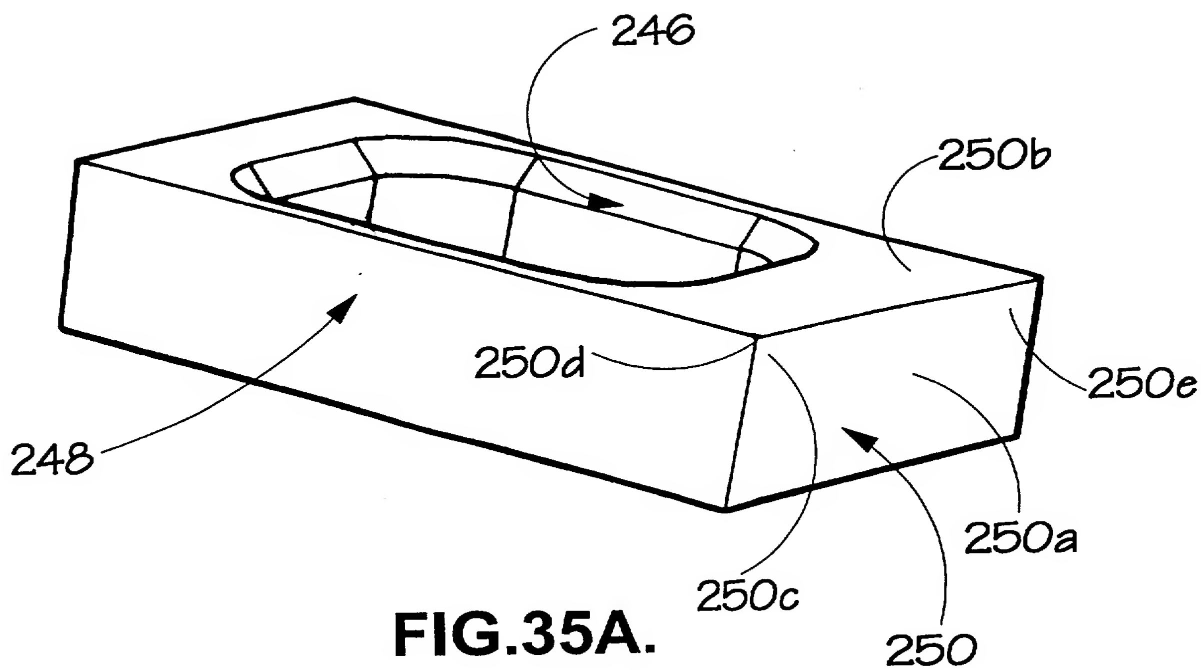


FIG.35A.

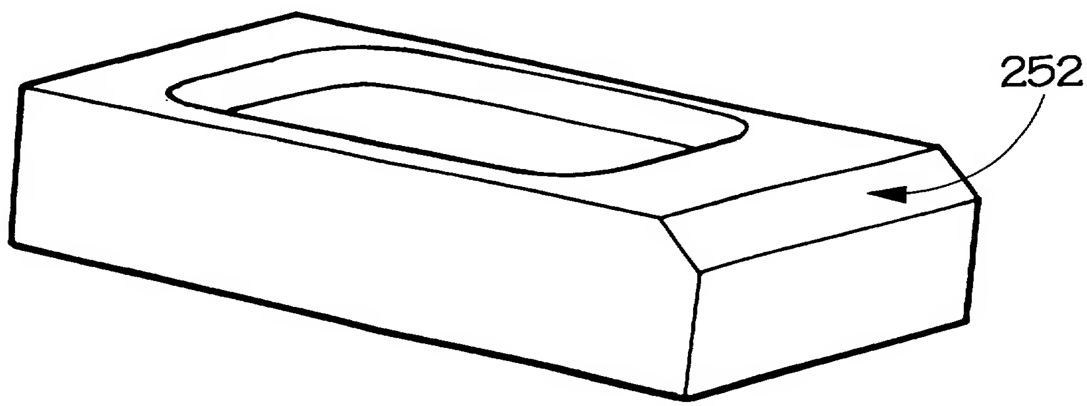


FIG.35B.

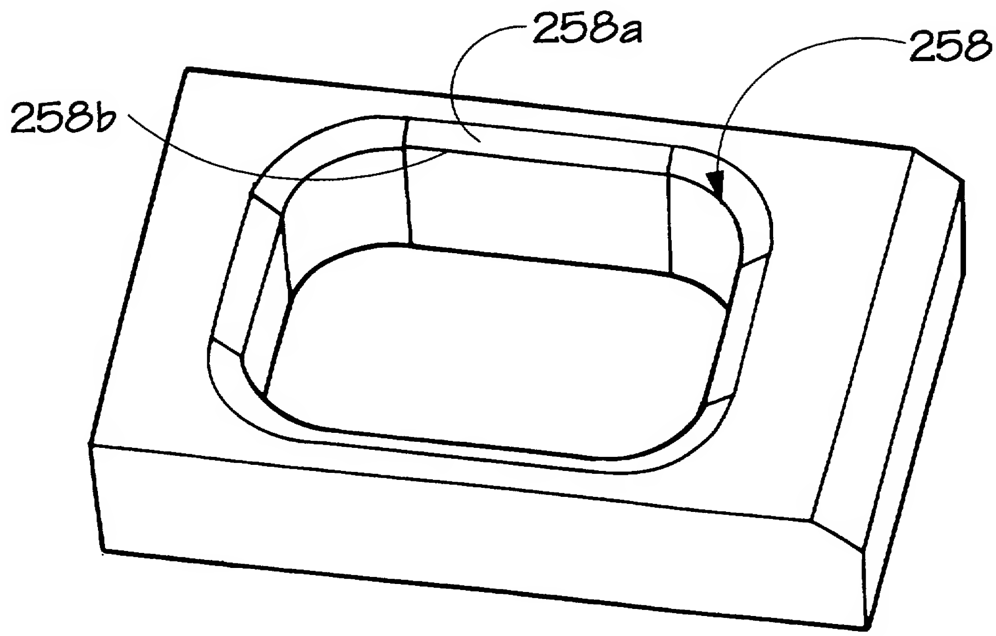


FIG.36A.

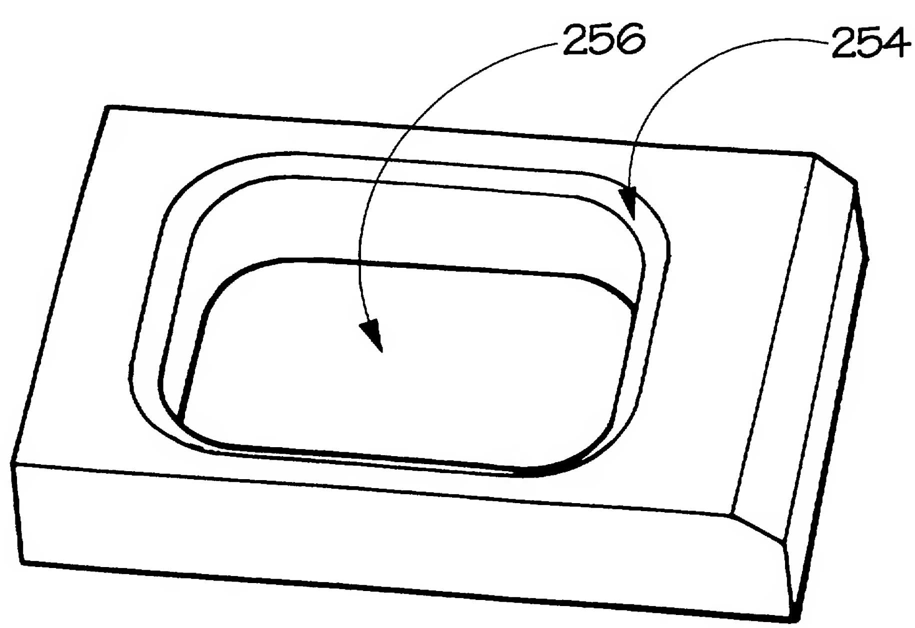


FIG.36B.

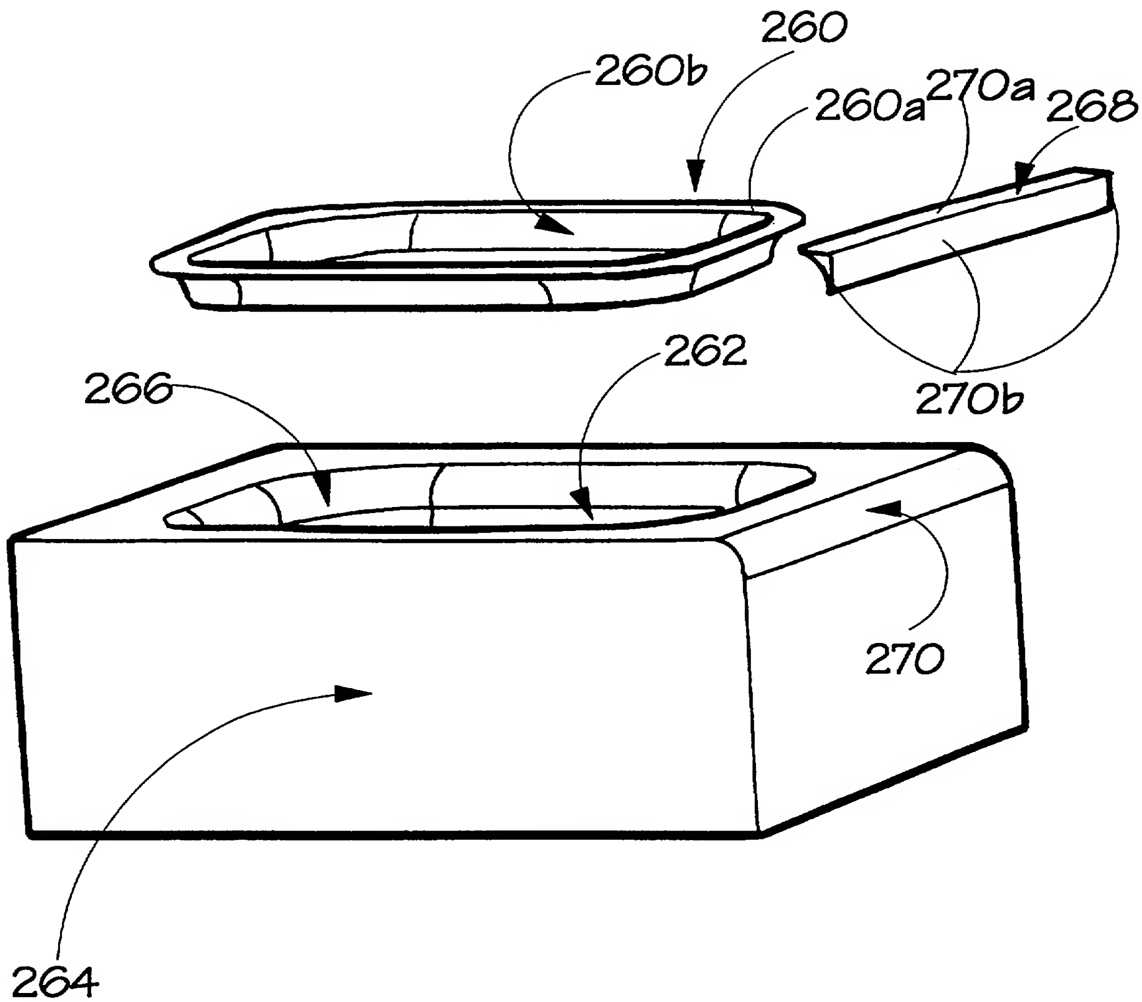


FIG.37.

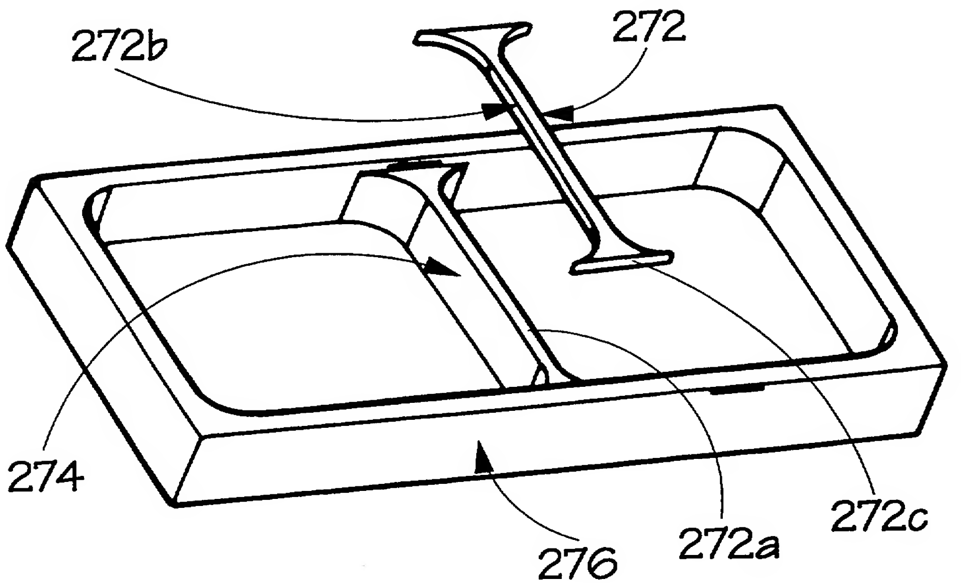


FIG.38A.

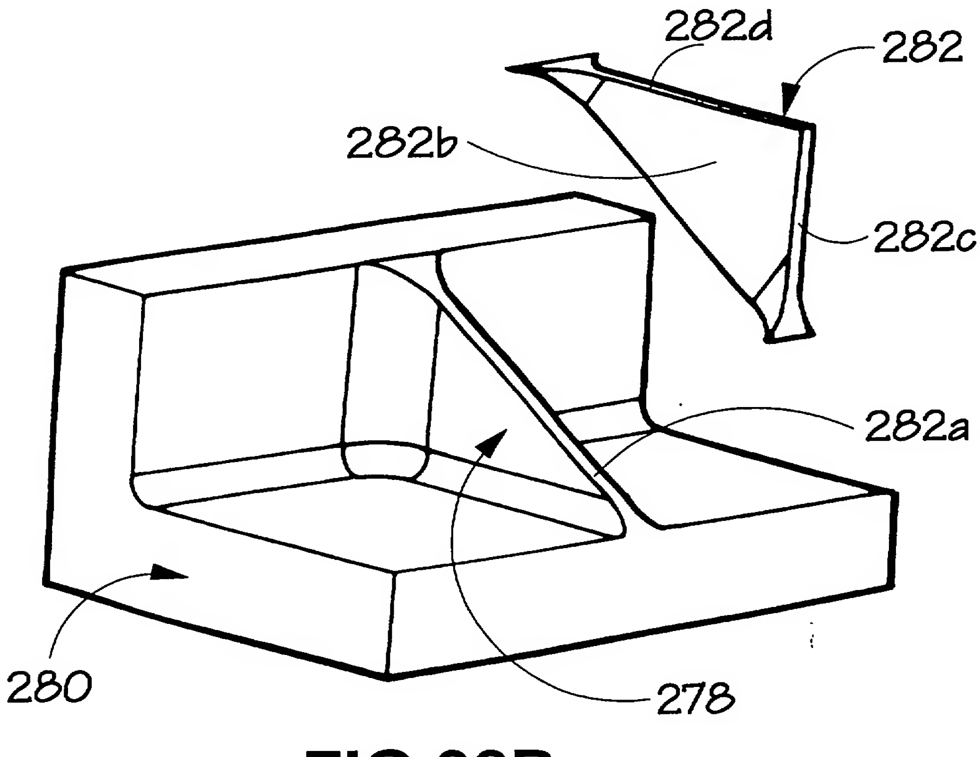


FIG.38B.

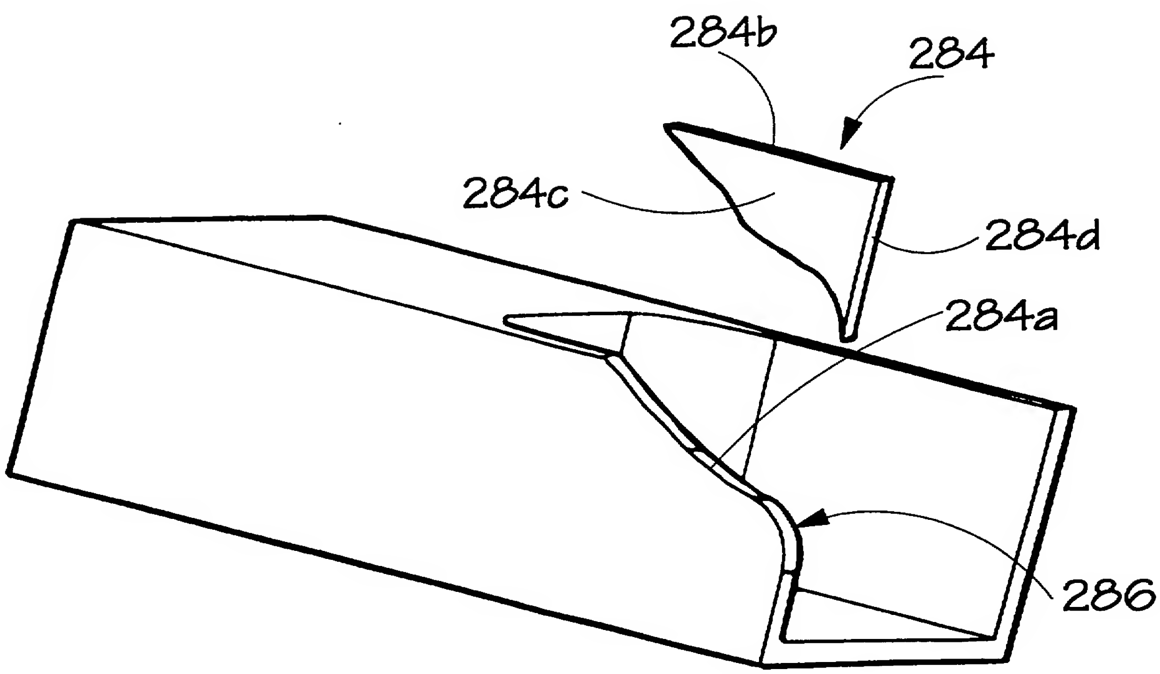


FIG.38C.

A COMPUTER-AIDED METHOD FOR GENERATING TOPOLOGICAL FEATURES FOR NUMERICALLY CONTROLLED MACHINING OF A WORKPIECE

This invention relates to providing a computer-aided method for generating a numerical control program for machining a work piece. More particularly, the present invention provides computer graphical tools and methods for aiding a user, such as a machinist, in machining a work piece.

Computer-aided manufacturing (CAM) systems employ numerically controlled machines for machining a work piece. When numerically controlled machines were first introduced, they required manual programming. That is, a programmer needed to calculate all the coordinates that a cutting tool of the machine had to traverse to cut the work piece, and to translate this information into a language that the machine tool could understand. This procedure was laborious and time-consuming.

Computer-assisted programming languages, such as Automatically Programmed Tools (APT), allow mathematical definition of geometries, e.g., lines, arcs, vectors, free-form curves, surfaces, etc, and allow programmatic driving of the cutting tool along such geometries. While such computer-assisted programs perform most of the mathematical calculations for generating a program for machining the work piece, they require the programmer to master the complex language of such computer-assisted programs. Many of the CAM systems in use today simply add graphics and efficient number-crunching capabilities to such manual and computer-assisted programming methods, and hence suffer from the foregoing disadvantages of such methods.

Another category of CAM systems employ automated numerical control programming that emerged with the advent of solid modeling technology. Such systems fall into two broad sub-categories, namely, generative numerical control (GNC) systems

and feature recognition systems. GNC systems attempt to apply methods such as artificial intelligence (AI) or case-based-reasoning (CBR) to a solid model of a work piece to automatically produce an optimal NC program for machining the work piece, thereby replacing the programmer. The use of such systems, however, is practical only within closely controlled conditions. Hence, such systems do not provide a general solution for automation of the machining process.

Unlike GNC systems, feature recognition systems do not attempt to completely replace the programmer. The programmer still needs to do the tedious job of generating tool paths. Such systems, however, do not allow the programmer to make certain critical decisions regarding machining the work piece. For example, such systems programmatically define the order of material removal from the work piece by analyzing a solid model of the work piece.

Hence, the traditional systems either do not sufficiently streamline the part programming process or automate the process to a degree that deprives the machinist of the ability to make certain critical decisions, such as the order in which to remove parts of the work piece, in regard to machining the work piece. This is particularly disadvantageous because it does not allow the machinist to take advantage of his/her experience in developing a strategy for machining the work piece.

The present invention provides a computer-aided method for machining a work piece to produce a physical object. The method of the invention provides a solid model of the physical object and a solid model of the work piece by employing graphical software, such as a computer aided design (CAD) system, e.g., a CAD/CAM system produced by Parametric Technology Corporation of Waltham, Massachusetts, U.S.A under the trade designation Pro/Engineer 2000i. Subsequently, the method of the invention combines the solid model of the object with the solid model of the work piece, for example by superimposing the two models, to provide a composite model that depicts volume portions of the work piece that need to be removed to create the object. This composite model is herein referred to as a numerical control (NC) model.

Further, the method of the invention provides a plurality of topological feature types in the graphical software for defining volume portions of the NC model as machining features having geometries that are topologically equivalent with at least one of the topological features. In particular, a human user employs the topological feature types to partition the volume portions of the NC model that are not included in the model of the object, i.e., the portions corresponding to volume portions of the work piece that need to be removed to create the object, into a plurality of machining features. In a preferred practice of the invention, the human user chooses at least one of the topological feature types and selects a surface of the NC model to associate a portion of the model having the selected surface with the chosen topological feature type. In this manner, the human user defines the portion having the selected surface as a machining feature that is topologically equivalent with the chosen topological feature type. Thus, the human user partitions the volume portions to be removed into a number of machining features. Further, the method of the invention provides tool paths for machining the machining features, to create the object.

According to one aspect of the invention, the topological feature types include a Face, a Slab, a Pocket, a Thru_Pocket, a Step, a Profile, a Channel, a Slot, a Boss Top, a Flange Face, a Hole Pattern, an Entry Hole, a Thru_Slot, an Undercut, a Rib Top, a Top Chamfer, a Top Round, an Open Contour, and a O-Ring Groove. Each of these feature types is defined below.

According to another aspect of the invention, a computer readable medium, such as a CD-ROM, a floppy disk, or a hard disk, is provided that holds computer-executable instructions for implementing the method of the invention.

In yet another aspect of the invention, a computer readable medium is provided that holds computer executable instructions for defining the topological feature types of the invention.

Another aspect of the invention relates to providing in a computer platform, a transmission medium for transmitting computer-executable instructions for performing a

method according to the present invention for assisting a human machinist in machining a work piece to produce an object.

Yet, another aspect of the present invention relates to providing in a computer system, a graphical user interface for allowing a user to choose at least one of a plurality of topological feature types, provided according to the teachings of the present invention, to define selected volume portions of a solid model, produced for example by a CAD system, such as the above-mentioned Pro/Engineer system produced by the Parametric Technology Corporation.

In accordance with another aspect of the invention, a CAM system is provided for assisting a human machinist in machining a work piece to produce an object. The CAM system includes a solid model of the work piece, a solid model of the object, and software for combining the solid models of the object and the work piece to produce an NC model depicting volume portions of the work piece that need to be removed to create the object. The CAM system further includes software for defining a plurality of topological feature types for partitioning selected volume portions of the NC model into a plurality of machining features in accordance with the method of the present invention. In addition, the CAM system includes software for producing tool paths for machining the plurality of the machining features. The tool paths consist of generic CL (Cutter Location) data that is post-processed into the specific language of the machine tool to be used (Machine Control Data – MCD).

A computer program for practicing the present invention can be written in any suitable programming language. Such a programming language can include, but is not limited to, C, C++, and Java™ (Java is a trademark of Sun Microsystems, Inc.). The method of the invention can be implemented by employing standard programming practices.

Specific embodiments of the present invention will now be described by way of example only, with reference to the accompanying drawings, in which:-

FIGURE 1 is a block diagram illustrating components of an exemplary computer system suitable for practicing the illustrative embodiment of the present invention.

FIGURE 2A is a solid model of an object to be formed by machining a work piece.

FIGURE 2B is a solid model of a workpiece from which the object of Figure 2A is to be formed.

FIGURE 3 is a Numerical Control (NC) model, which is a combination of the solid models of Figures 2A and 2B.

FIGURE 4 is a toolbar of a graphical user interface according to the teachings of the present invention depicting icons for selecting various topological features of the invention.

FIGURE 5A is a dialogue box that appears upon selection of the icon representing a Face feature from the toolbar of Figure 4, and allows a machinist to define a Face machining feature.

FIGURE 5B illustrates defining a volume portion of the NC model of Figure 3 as a Face machining feature.

FIGURE 5C illustrates the NC model of Figure 3 with the Face feature of Figure 5B removed.

FIGURE 6A is a dialogue box that appears upon selection of the icon representing a Step topological feature from the toolbar of Figure 4, and allows a machinist to define a Step machining feature.

FIGURE 6B illustrates defining a volume portion of the NC model to be removed as a Step machining feature.

FIGURE 6C illustrates the NC model of Figure 3 with the Face feature of Figure 5B and the Step feature of Figure 6B removed.

FIGURE 7A is a dialogue box that appears upon selection of the icon representing a Profile topological feature from the toolbar of Figure 4, and allows a machinist to define a Profile machining feature.

FIGURE 7B illustrates defining a volume portion of the NC model to be removed as a Profile machining feature.

FIGURE 7C illustrates the NC model of Figure 3 with the Face feature of Figure 5B, the Step feature of Figure 6B, and the Profile feature of Figure 7B removed.

FIGURE 8A is a dialogue box that appears upon selection of the icon representing a Pocket topological feature from the toolbar of Figure 4, and allows a machinist to define a Pocket machining feature.

FIGURE 8B illustrates defining a volume portion of the NC model to be removed as a Pocket machining feature.

FIGURE 8C is a top plan view of the Pocket feature of Figure 8B.

FIGURE 8D illustrates the NC model of Figure 3 with the Face feature of Figure 5B, the Step feature of Figure 6B, the Profile feature of Figure 7B, and the Pocket feature of Figure 8B removed.

FIGURE 9A is a dialogue box that appears upon selection of the icon representing a Thru_Pocket topological feature from the toolbar of Figure 4, and allows a machinist to define a Thru_Pocket machining feature.

FIGURE 9B illustrates defining a volume portion of the NC model to be removed as a Thru_Pocket machining feature.

FIGURE 9C is a top plan view of the NC model of figure 9B, depicting the hard walls of the Thru_Pocket feature of figure 9B.

FIGURE 9D illustrates the NC model of Figure 3 with the Face feature of Figure 5B, the Step feature of Figure 6B, the Profile feature of Figure 7B, and the Pocket feature of Figure 8B, and the Thru_Pocket feature of Figure 9B removed.

FIGURE 10A is a perspective view of the NC model of figure 3 including a design model enclosed within a workpiece, depicting a Thru_Pocket feature extending across the entire width of the workpiece.

FIGURE 10B is a perspective view of the NC model of the previous figure, depicting a Step feature defined in the NC model subsequent to defining the Thru_Pocket feature of the previous figure.

FIGURE 11A is a perspective view of the NC model of the previous figure, depicting a Step machining feature created in the NC model.

FIGURE 11B is a top plan view of the Step machining feature of the previous figure, depicting the hard and the soft walls of the feature.

FIGURE 11C illustrates the NC model of figure 11A with the Step machining feature of figure 11B removed.

FIGURE 12A is a perspective view of the NC model of figure 3, a volume portion of which is defined as another Step machining feature.

FIGURE 12B is a top plan view of the Step feature defined in the previous figure, depicting the hard and the soft walls of the feature.

FIGURE 12C illustrates the NC model of figure 12A with the Step feature of figure 12B removed.

FIGURE 13A is a perspective view of the NC model of figure 3, depicting a prism-like volume portion defined as a Step machining feature.

FIGURE 13B is a top plan view of the Step machining feature of figure 13A, depicting the hard walls and the soft walls of the feature.

FIGURE 13C illustrates the NC model of figure 13A, with the Step machining feature of figure 13B removed.

FIGURE 14A is a perspective view of the NC model of figure 3, depicting a ledge section as a Step machining feature.

FIGURE 14B is a top plan view of the Step feature of the previous figure, depicting the hard and the soft walls of the feature.

FIGURE 15A illustrates the NC model of figure 14A, with the Step feature of figure 14B removed, depicting the remaining volume portions to be removed as dark sections.

FIGURE 15B illustrates the NC model of the previous figure after removal of the remaining volume portions to be removed as three Hole patterns to obtain the design model shown in Figure 2A.

FIGURE 16A illustrates a tool path created according to the teachings for machining the Step feature of figure 6.

FIGURE 16B is a top plan view of the tool path shown in Figure 16A.

FIGURE 17 is a dialogue box provided by a preferred method of the invention containing a list of some of the machining features depicted in the previous figure.

FIGURE 18A is a perspective view of an NC model that includes the design model of figure 2 enclosed within a workpiece whose peripheral surfaces extend beyond the peripheral surfaces of the design model, depicting the peripheral volume portion to be removed from the workpiece as a Profile machining feature.

FIGURE 18B illustrates the NC model of figure 18A after removal of the Profile feature depicted in figure 18A.

FIGURE 19A is a perspective view of an NC model, depicting a volume portion to be removed as a Slot machining feature.

FIGURE 19B is a top plan view of the Slot feature of the previous figure, depicting the hard and the soft walls of the feature.

FIGURE 19C illustrates a portion of the NC model of figure 19A after removal of the Slot feature defined in figure 19B.

FIGURE 20A is a fragmentary perspective view of an NC model, depicting a volume portion of the model to be removed as a Slot feature having two chains of hard walls that are normal constant offset of each other, a hard wall that is a full radius, and a soft wall opposite to the wall that is a full radius.

FIGURE 20B is a top plan view of the Slot feature of figure 20A, depicting the hard and the soft walls of the feature.

FIGURE 20C is a fragmentary view of the NC model of figure 20A after removal of the Slot feature of figure 20A.

FIGURE 21A is a fragmentary perspective view of an NC model, a volume portion of which is defined as a Slot feature having two hard walls that are constant offset of each other, and two opposed hard walls, each of which is a full radius.

FIGURE 21B is a perspective view of the Slot feature of figure 21A illustrating the surfaces forming the feature.

FIGURE 21C illustrates the hard walls of the Slot feature of the previous figure.

FIGURE 21D is a fragmentary view of the NC model of figure 21A with the Slot feature removed.

FIGURE 22A is a perspective view of an NC model, a volume portion of which is defined as a Channel feature, after creation of a Pocket feature and a Thru_Pocket feature, in accordance with the teachings of the invention.

FIGURE 22B is a top plan view of the Channel feature of figure 22A, depicting the hard and soft walls of the feature.

FIGURE 22C illustrates the NC model of figure 22A with the channel feature removed.

FIGURE 23 is a dialogue box provided by the method the invention upon selection of an icon representing a Hole Pattern feature from the toolbar of figure 4 by a machinist.

FIGURE 24A is a perspective view of an NC model, volume portions of which are defined as a Hole Pattern feature.

FIGURE 24B illustrates the NC model of figure 24A after removal of the Hole Pattern feature.

FIGURE 25A is a perspective view of an NC model, a volume portion of which is defined as a Slab feature.

FIGURE 25B is a top plan view of the Slab feature of the previous figure.

FIGURE 25C illustrates the NC model of figure 25A after removal of the Slab machining feature.

FIGURE 26A is a dialogue box that the method of the invention provides upon selection of an icon representing an Entry Hole from the toolbar of figure 4 by a machinist.

FIGURE 26B is a perspective view an NC model depicting an Entry Hole feature within a Pocket feature.

FIGURE 27A is a dialogue box that the method of the invention provides upon selection of an icon representing a Flange Face feature from the toolbar of figure 4 by a machinist.

FIGURE 27B is a perspective fragmentary view of an NC model, illustrating a Flange Face feature according to the teachings of the invention.

FIGURE 27C is top plan view of the Flange Face feature of the previous figure.

FIGURE 27D illustrates the NC model of figure 27A after removal of the Flange Face feature.

FIGURE 28A is a perspective view of a design model, a volume of which is defined as a Thru_Slot feature according to the teachings of the present invention.

FIGURE 28B is a top view of the Thru_Slot feature of FIGURE 28A.

FIGURE 29 is a perspective view of the design model of Figure 28A with the Thru_Slot feature of Figure 28A removed.

FIGURE 30A is a perspective view of the design model of Figure 28A in which a second Thru_Slot feature is defined.

FIGURE 30B is a perspective view of the design model of Figure 30A after removal of the second Thru_Slot feature shown in Figure 30A.

FIGURE 31A is a dialogue box that appears upon selection of the icon representing a Boss Top feature from the toolbar of Figure 4.

FIGURE 31B is a perspective view of a design model in which a volume portion within a Pocket feature is defined as a Boss Top machining feature.

FIGURE 31C is a perspective view of the design model of Figure 31B with the Boss Top machining feature shown in Figure 31B removed.

FIGURE 32A is a perspective view of an NC model in which a volume portion is defined as an O-Ring Groove machining feature.

FIGURE 32B is a top view of the O-Ring Groove feature of Figure 32A.

FIGURE 32C is a perspective view of the NC model of Figure 32A with the O-Ring Groove feature shown in Figure 32A removed.

FIGURE 33 is a perspective view of a model in which a volume portion is defined as an Open Contour feature.

FIGURE 34 is a perspective view of a design model, a volume portion of which, defined as an Undercut machining feature according to the teachings of the invention, is removed.

FIGURE 35A is a perspective view of an NC model in which a volume portion to be removed is defined as a Top Chamfer machining feature.

FIGURE 35B is a perspective view of the design model of Figure 35A having a chamfer created by removal of the volume portion defined as a Top Chamfer feature as shown in Figure 35A.

FIGURE 36A is a perspective view of the NC model of Figure 35A in which a volume portion surrounding a Thru_Pocket feature is defined as a Top Chamfer machining feature.

FIGURE 36B illustrates the NC model of Figure 35A after removal of the Top Chamfer feature.

FIGURE 37 is a perspective view of a design model and two volume portions defined as Top Round machining features.

FIGURE 38A is a perspective view of a design model having a Rib design feature produced by removing a volume portion defined as a Rib Top machining feature.

FIGURE 38B is a perspective view of a design model having a Rib design feature produced by removing a volume portion defined as a Rib Top machining feature.

FIGURE 38C is a perspective view of a design model having a fee-form Rib design feature produced by removing a volume portion defined as a Rib Top machining feature.

A computer implemented method according to the teachings of the present invention assists a human machinist in machining a workpiece to create a physical object. In particular, a human machinist can advantageously interact with software implementing the method of the invention to partition volume portions of the workpiece that need to be removed, depicted in a combined model of the workpiece and the object, into smaller, more manageable volume portions that lend themselves to shop-floor-accepted machining practices. These smaller volume portions are herein referred to as machining features. The method of the invention automatically builds these machining features upon a user's selection of particular topological features provided by the invention, and selection of one or more surfaces of the design model. The machining

features of the invention advantageously include hard and/or soft surfaces that allow creation of an optimal toolpath for machining the workpiece, as described below.

FIGURE 1 is a block diagram that shows the components of an exemplary computer system 10 for practicing the illustrative embodiment. The computer system 10 includes a central processing unit (CPU) 12 for executing instructions. A number of peripheral devices, including a keyboard 14, a video display 16, and a mouse 18, may be provided as part of the computer system 10. A modem 20 may be provided to allow the computer system 10 to communicate over analog telephone lines, and a network adapter 22 may be provided to facilitate the connection of the computer system 10 to a local area network (LAN). The computer system 10 may further include other components, such as a cable modem, for facilitating remote communications with a remote server (not shown).

The computer system 10 includes both primary storage 24 and secondary storage 26. The secondary storage 26 may include a number of different types of persistent storage. For example, the secondary storage 26 may include CD-ROM, floppy disks, hard disks and/or any other suitable computer-readable medium, including other devices that use optical, magnetic or other recording material. The primary storage 24 may also include a number of different types of storage, such DRAM, SRAM, and the like.

The computer system 10 further includes a facility for generating a solid model of a physical object. For example, a CAD system, such as the system produced by Parametric Technology Corporation of Waltham, Massachusetts, U.S.A (herein "PTC") under the trade designation Pro/Engineer 2000i, can be stored in the secondary storage 26 to be utilized for producing a model of a work piece and/or an object to be produced by machining the work piece.

The secondary storage device 26 can also include executable instructions for defining a plurality of topological features according to the present invention and instructions for creating tool paths for machining selected volume portions of a workpiece, as described below. In a preferred embodiment, such executable instructions are incorporated into a CAM system to assist a machinist in machining a work piece.

Those skilled in the art will appreciate that the computer system 10, shown in FIGURE 1, is intended to be merely illustrative and not limiting of the present invention.

An illustrative example of the practice of the method of the illustrative embodiment will be presented below with reference to a solid model 28 of a physical object (FIGURE 2A), herein referred to as a design model, and a solid model 30 of a work piece (FIGURE 2B), also known as a stock model, from which the object is to be formed. The workpiece can be, for example, a slab of aluminum or the like. A preferred practice of the invention employs a CAD system to produce the solid models 28 and 30.

The method of the invention combines the solid models 28 and 30, as shown in FIGURE 3, to produce a composite model 32, herein referred to as a numerical control (NC) model, depicting volume portions of the workpiece that need to be removed to create the object 28. A human machinist can employ the NC model 32 and various topological features provided by the present invention, as described below, to partition the volume portions to be removed into a plurality of machining features.

The topological features provided by the method of the invention, and employed in the illustrative embodiment described below, include a Face, a Slab, a Pocket, a Thru-Pocket, a Step, a Profile, a Channel, a Slot, a Boss Top, a Flange Face, a Hole Pattern, an Entry Hole, a Thru-Slot, an Undercut, a Rib Top, a Top Chamfer, a Top Round, an Open Contour, and a O-Ring Groove.

Each topological feature is defined with reference to the properties of the surfaces of a solid model that bound a volume element defined by the feature. The bounding surfaces of a volume element are herein referred to as a top, a floor, and walls. These surfaces are herein defined with reference to an XYZ Cartesian coordinate system. In particular, a top, as used herein, refers to a bounding surface of the volume element having an average value of the Z coordinate (averaged over all points of the surface) that is larger than the average value of the Z coordinate of the other surfaces. A floor is a surface having the lowest average value of the Z coordinate. The remaining bounding surfaces are herein referred to as walls.

A plurality of surfaces form a closed loop if they are contiguous, and each surface has two adjacent surfaces. A single surface forms a closed loop if it is folded such that its beginning and its end meet. For example, a single cylindrical surface forms a closed loop. Each surface surrounding the volume element can be either a hard surface or a soft surface. The adjective "hard", as used herein, for describing a surface of a solid model refers to a surface of the model corresponding to a surface of the object through which a tool bit, such as a milling bit, can not penetrate; and the adjective "soft", as used herein, for describing a surface of a solid model, refers to a surface through which a tool bit can penetrate. Further, the phrase "chain of walls", as used herein, refers to either a single wall or multiple adjacent walls of the same type, i.e., either hard or soft. A chain of walls can form either open or closed loops. An island refers to a closed loop of hard walls that are fully contained by the floor of the topological feature.

The various topological features of the invention are defined as follows. A Face feature includes a hard floor and a soft top, and a single chain of soft walls that is the outermost chain of soft walls found by the method of the invention and that form a closed loop.

A Slab feature includes a hard floor and a soft top, and further includes some hard walls and some soft walls. For example, a Slab feature can include multiple, alternating chains of hard and soft walls that form a closed loop. In such a case, a Slab feature may include islands. Alternatively, a Slab feature can include a single chain of soft walls that form a closed loop. In this case, islands are necessarily present.

A Pocket feature includes a hard floor and a soft top, and further includes a single chain of hard walls that form a closed loop.

A Thru_Pocket feature includes a soft floor and a soft top, and further includes a single chain of hard walls that form a closed loop.

A Step feature includes a hard floor and a soft top. Further, a Step feature can include a single chain of soft walls and a single chain of hard walls that together form a closed loop. Alternatively, a Step feature can include a single chain of hard walls that form a closed loop, and a single chain of soft walls that do not intersect the hard walls and also form a closed loop.

A Profile feature includes a soft floor and a soft top. Further, a Profile feature can include a single chain of soft walls and a single chain of hard walls that together form a closed loop. Alternatively, a Profile feature can include a single chain of soft walls and a single chain of hard walls that do not intersect, and where the hard walls together form a closed loop and the soft walls together form a separate closed loop.

A Channel feature includes a hard floor and a soft top. A Channel feature further includes multiple alternating chains of hard and soft walls that together form a closed loop, where at least two chains of each type, i.e., hard and soft, are required.

A Slot feature includes a hard floor and a soft top. Under a first set of conditions, a Slot feature can include multiple alternating chains of hard and soft walls that together form a closed loop, and where only two chains of each type, i.e., hard or soft, are present and one chain of hard walls is a normal constant offset of the other chain. A surface is herein characterized as a normal constant offset of another surface if any vector originating on any of the surfaces and normal to that surface intersects the other surface at a normal angle, and further all such vectors have the same length. Alternatively, under a second set of conditions, a Slot feature can include one chain of soft walls and three chains of hard walls that together form a closed loop. The chain of hard walls opposite the chains of soft walls must be a full radius, i.e., it must have a generally semi-cylindrical shape, and the remaining two chains of hard walls must be normal constant offset of each other. Under a third set of conditions, a Slot can include four chains of hard walls that together form a closed loop. Two of these chains that are opposite from each other must each form a full radius equal to each other. Further, the remaining two chains of hard walls must be normal constant offset of each other.

A Boss Top feature includes a hard floor and a soft top. Further, a Boss Top feature includes a single chain of soft walls that together form a closed loop, where the soft walls are the closest chain of soft walls to the floor.

A Flange Face feature includes a hard floor and a soft top. Further, a Flange Face feature can include two chains of soft walls that do not intersect, and each forms a closed loop. Alternatively, a Flange Face can include a single chain of soft walls and a single chain of hard walls that do not intersect, and where each chain forms a separate closed loop, with the chain of hard walls fully contained within the chain of soft walls.

While a Hole Pattern feature may include a hard floor or a soft floor, it must necessarily include a soft top. Further, a Hole Pattern feature includes a set of one or more hard cylindrical walls, each disjointed from the others.

An Entry Hole feature may include a hard or a soft floor, but must necessarily include a soft top. Further, an Entry Hole feature can include a single opening created in an existing Pocket, or in a Thru_Pocket, or in an existing Slot that includes four chains of hard walls which together form a closed loop, or in an O-Ring Groove.

A Thru_Slot feature includes a soft floor and a soft top. Further, a Thru_Slot feature can include one chain of soft walls and three chains of hard walls that together form a closed loop. The chain of hard walls opposite the chain of soft walls each must be a full radius. The remaining two chains of hard walls must be normal constant offset from each other. Alternatively, a Thru_Slot can include four chains of hard walls that together form a closed loop. Each wall of two of these chains forms a full radius with a radius equal to that of the other. The remaining two chains of hard walls must be normal constant offset from each other.

While the floor of an Undercut feature may be either hard or soft, its top must be a hard surface. Further, an Undercut feature includes one chain of soft walls and one chain of hard walls that together form a closed loop.

A Rib Top includes a hard floor and a soft top. Further, a Rib Top can include a single chain of soft walls that together form a closed loop. Alternatively, a Rib Top can include a single chain of soft walls and a single chain of hard walls that together form a closed loop. Yet, alternatively, a Rib Top can include multiple, alternating chains of soft and hard walls that together form a closed loop.

A Top Chamfer feature has a triangular cross-section, and includes a hard floor, formed of a chain of hard planar surfaces, and a soft top. Further, a Top Chamfer includes a chain of soft walls.

A Top Round feature includes a hard floor, formed of a chain of hard cylindrical surfaces, and a soft top. A Top Round further includes a single chain of soft walls. A Top Round has a convex cylindrical floor.

An Open Contour feature includes a hard floor and a soft top. An Open Contour feature is a special case of either a Face feature or a Slab feature, and hence it satisfies the conditions of one of these features. In addition, the hard floor of an Open Contour feature is either a non-planar surface, or a planar surface that is not normal to the Z-axis of the active coordinate system, i.e., a canted surface.

An O-Ring Groove feature includes a hard floor and a soft top. Further, a O-Ring Groove feature includes two chains of non-intersecting hard walls, where each chain is a normal constant offset of the other, and each chain forms a closed loop.

FIGURE 4 illustrates a toolbar 34 of a graphical user interface (GUI) according to the present invention that includes a plurality of icons for selecting the topological features provided by the invention. In particular, an icon 36 represents a Pocket feature, an icon 38 represents a Thru_Pocket feature, an icon 40 represents a Channel feature, an icon 42 represents a Slot feature, an icon 44 represents a Step feature, an icon 46 represents a Face feature, an icon 48 represents a Slab feature, an icon 50 represents a Flange Face feature, an icon 52 represents a Profile feature, an icon 54 represents a Boss Top feature, an icon 56 represents a Hole Pattern feature, and an icon 58 represents an Entry Hole feature. Icons 60, 62, and 64 are not related to feature definition, but rather

provide other functions. In particular, the icon 60 can be selected to display the NC model after removal of all defined features. The icon 62 can be selected to create a tool path that is not associated with a defined feature. In particular, selection of the icon 62 allows a user to sketch a path for the cutting tool to follow, or pick the existing edges of the NC model for the tool to follow. The icon 64 can be selected to provide a list of defined features. Selection of a feature on this list allows the user to create a tool path for machining the feature.

A human user, such as a machinist, can choose one or more of the topological features to define machining features that partition the volume portions of the NC model 32 that need to be removed. For example, as a first step in machining the work piece 30, the machinist can choose a topological feature defining a Face feature by selecting the illustrative icon 46 in the toolbar 34.

With reference to FIGURES 4, 5A, 5B, and 5C, upon selecting the icon 46, a dialogue box 46a appears, with the Define Feature Floor option preferably preselected, that prompts the machinist to select a surface of the design model that constitutes the hard floor of a volume portion to be defined as a Face machining feature; and further provides the machinist with the opportunity to name this machining feature.

In this illustrative example, the machinist selects a horizontal, i.e., perpendicular to the Z axis, surface 66 of the design model as the hard floor of a volume portion 68 having a parallelepiped shape with a height h, a length l, and a width w, to be defined as a Face machining feature, herein named Face1.The method of the invention then automatically defines peripheral vertical, i.e., parallel to the Z axis, surfaces 70, 72, 74, and 76 of the volume portion 68 as the soft walls of the Face machining feature; and further defines a horizontal surface 78, displaced by a distance h along the positive Z axis from the hard floor 66, as the soft top of the Face feature 68. Thus, the method of the invention allows the machinist to define the volume element 68 as a Face machining feature by selecting only the hard floor 64, while the method of the invention automatically finds the other surfaces of the Face feature and determines whether they are hard or soft surfaces. Although this exemplary Face machining feature has a parallelepiped shape, those skilled in the art will understand that a Face feature

according to the invention can have any shape. This interplay between the human machinist and the computer implemented method of the invention provides advantages over many conventional feature-based manufacturing systems. Such conventional systems typically either require all surfaces of a feature to be selected manually, which is a very cumbersome and time-consuming process, or attempt to create the feature completely automatically, which is rarely successful in all but the simplest cases.

FIGURE 5C illustrates the NC model 32 after removal of the Face machining feature 68. The dark sections, such as sections 32a and 32b, depict the remaining volume portions of the work piece that need to be removed to produce the physical object 28. These remaining volume portions will be defined in accordance with other topological features of the invention, as described above.

With reference to FIGURES 4, 6A, 6B, and 6C, in the illustrative embodiment of the invention, the machinist, subsequent to forming the Face feature 68, can select an icon 44 from the toolbar 34 corresponding to a Step topological feature, to obtain a dialogue box 44a. A Step topological feature, as described above, includes a hard floor, and a soft top. Further, one embodiment of a Step feature includes a single chain of soft walls and a single chain of hard walls that in combination with the soft walls form a closed loop. The machinist selects a horizontal surface 80 of the design model 28 to be the hard floor of a volume portion to be defined as a Step machining feature. Upon selection of the hard floor 80 by the machinist, the method of the invention automatically selects a single chain of hard walls 82 including surfaces 82a, 82b, 82c, 82d, 82e, 82f, and 82g; a single chain of soft walls 84 including vertical surfaces 84a and 84b; and a soft top 86, which is a portion of the floor of the Face feature 68 subtended by the hard walls 82 and the soft walls 84, to form a Step machining feature 88. Although in this example, the Step feature 88 is defined subsequent to formation of the Face feature 68, those skilled in the art will understand that the method of the invention provides the machinist with full control over the order in which various features are defined.

FIGURE 6C illustrates the NC model 32 after removal of the Face feature 68 and the Step feature 88, herein named the Large Step, depicting the remaining volume portions to be removed as dark sections.

With reference to FIGURES 4, 7A, 7B, and 7C, subsequent to forming the Step feature 88, the machinist can select an icon 52 from the toolbar 34 representing a Profile topological feature. Upon selection of the Profile topological feature 52, a dialogue box 52a appears that prompts the machinist to choose one or more surfaces of the design model 28 as the hard walls of a volume portion of the NC model 30 to be defined as a Profile machining feature. In the illustrative embodiment, the machinist defines a single chain of surfaces 90a, 90b, and 90c as the hard walls of the volume portion to be defined as a Profile machining feature, for example by choosing the surface 90b. The method of the invention automatically selects a single chain of soft walls 92a and 92b, a soft top 94 and a soft floor 96 to form a Profile machining feature 98. The soft wall 92b is a portion of a side wall of the workpiece 30 subtended by the soft wall 92a and the hard wall 90a; and the soft floor 96 is a portion of the bottom surface of the workpiece 30 subtended by the hard walls 90a, 90b, 90c, and the soft walls 92a and 92b. The hard walls 90a, 90b, and 90c in combination with the soft walls 92a, and 92b of the Profile feature 98 form a closed loop. In this illustrative embodiment, selection of only one of the hard surfaces 9-90a, 90b, or 90c is sufficient for the method of the invention to build the Profile feature 98. In general, a machinist may need to select more than one hard surface to provide sufficient information to the method of the invention for building a Profile feature.

FIGURE 7C illustrates the NC model 32 after removal of the Face feature 68, the Step feature 88, and the Profile feature 98. The dark sections depict the remaining volume portions of the NC model that need to be removed to obtain the physical object 28.

Reference to FIGURE 8B shows that the design model 28 includes a central opening 100 that is formed of an upper portion subtended by a single chain of walls 102 ,and a lower portion subtended by a single chain of walls 104 that is separated from the single chain of walls 102 by a ledge 106. The method of the invention advantageously

provides the possibility of selecting alternative features for defining a volume element to be removed. For example, a machinist can employ either a combination of a Pocket feature and a Thru_Pocket feature, or alternatively, a combination of a Thru_Pocket feature and a Step feature to define machining features corresponding to the central opening 100, as described below. The flexibility provided by the method of the invention in selecting alternative features for defining a volume element is advantageous because it allows the machinist to employ prior machining experience and knowledge of the machining environment to optimally machine a volume element.

To define the central opening 100 through a combination of a Pocket feature and a Thru_Pocket feature, the machinist can first select an icon 36 from the toolbar 34 (FIGURE 4) that corresponds to a Pocket topological feature. A Pocket feature, as described above, includes a hard floor, a soft top, and hard walls. With reference to FIGURES 8A, 8B, and 8C, upon selection of the Pocket feature 36, a dialogue box 36a, with the Define Feature Floor option preferably pre-selected, appears. The machinist selects the ledge 106 to define a hard floor, which includes the ledge 106 and is subtended by the chain of walls 102, as a volume portion to be defined as a Pocket feature. Upon selection of the hard floor, the method of the invention automatically selects the single chain of hard walls 102, including surfaces 102a, 102b, 102c, 102d, 102e, 102f, 102g, 102h, 102I, and 102j (FIGURE 8C) forming a closed loop; and a soft top 108, which is a portion of the Face feature 68 subtended by the chain of walls 102 and displaced from the hard floor 106a along the positive Z-axis by a width h1 of the single chain of hard walls 102, to form a Pocket machining feature 110.

FIGURE 8D illustrates the NC model 32 after removal of the Face feature 68, the Step feature 88, the Profile feature 98, and the Pocket feature 110. The dark sections depict the remaining volume portions that need to be removed to create the object 28.

With reference to FIGURES 9A, 9B, 9C, and 9D, in a subsequent step of the illustrative embodiment, the machinist selects a topological feature corresponding to a Thru_Pocket, for example by selecting the icon 38 from the toolbar 34, which causes a dialogue box 40a to appear (FIGURE 9A). As described above, a Thru_Pocket includes a soft floor, a soft top, and a single chain of hard walls forming a closed loop. The

machinist can select one of the surfaces forming the single chain of walls 104, for example the surface 104a, to define a single chain of hard walls for a volume portion to be defined as a Thru_Pocket machining feature. Upon selection of the surface 104a as a hard wall, the method of the invention automatically selects the surfaces 104b , 104c, 104d, 104e, 104f, 104g, 104h, 104i, and 104j as the surfaces that, in combination with the surface 104a, form a single chain of hard walls of the Thru_Pocket machining feature. Further, the method of the invention automatically selects a soft top 112, bounded by the ledge 106, which is a portion of the floor of the Pocket feature 110, extending between the upper and the lower portions of the central opening 100, and a soft floor 114 to build a Thru_Pocket feature 116 that extends through the work piece 28. Those skilled in the art will understand that a partial automation can also be employed to select other surfaces of the Thru_Pocket feature after selection of its hard floor.

FIGURE 9D shows the NC model 32 after removal of the Face feature 68, the Step feature 88, the Profile feature 98, the Pocket feature 110, and the Thru_Pocket feature 116, illustrating that the central opening 100 can be formed by removal of the Pocket feature 110 and the Thru_Pocket feature 116. The dark sections depict the remaining volume portions that need to be removed from the work piece 30 to form the object 28.

Alternatively, the central opening 100 can be formed by characterizing the volume element to be removed from the workpiece 30 as a combination of a Thru_Pocket feature and a Step feature. In particular, FIGURE 10A shows that the machinist can first define a Thru_Pocket feature 118 that extends across the entire width h of the workpiece 30 by selecting, for example, the surface 104a of the design model 28. Upon such a selection, the method of the invention selects surfaces 104b, 104c, 104d, 104e, 104f, 104g, 104h, 104i, and 104j, and extends each of these surfaces and the selected surface 104a across the entire width h of the workpiece 28 to create the chain of hard walls of the Thru_Pocket feature 118. Further, the method of the invention selects a portion 120 of the upper surface of the workpiece 28 that is subtended by the intersection of the chain of hard walls of the Thru_Pocket feature 118 with the upper surface of the workpiece as a soft top of the Thru_Pocket feature 118. In a similar

manner, the method of the invention selects a portion of a lower surface of the workpiece 28 that is subtended by the intersection of the chain of hard walls with the lower surface as a soft floor 122 of the feature 118.

After forming the Thru_Pocket feature 118, a Step feature 124 (FIGURE 10B) can be defined by selecting the icon 44 from the toolbar 34 and the ledge 108 as input to the method of the invention. Upon such a selection by the machinist, the method of the invention builds the Step feature 124 by defining the ledge 108 a the hard floor of the feature, and selecting the surfaces 102a, 102b, 102c, 102d, 102e, 102f, 102g, and 102h forming a closed loop, as the hard walls of the Step feature 124. The method further selects portions of the chain of walls of the Thru_Pocket 118 extending above the ledge 108 as a chain of soft walls of the Step feature 124. A portion 126 of the upper surface of the workpiece 28 subtended by the chain of hard walls and soft walls of the Step feature 124 forms a soft top of the Step feature 124. Thus, the Step feature 124 includes a single chain of hard walls that form a closed loop, and a single chain of soft walls that do not intersect the hard walls and also form a closed loop. Removal of the Thru_Pocket 118 and the Step feature 124 provides the central opening 100.

Those skilled in the art will understand that formation of the Step feature 124 must follow the formation of the Thru_Pocket feature 118, because the chain of soft walls of the Step feature 124 can only be defined after creating the Thru_Pocket 118. This illustrates that under certain conditions, various machining features that collectively define a volume element of the workpiece must be defined in a particular order. Further, this illustrates that the method of the invention advantageously allows, in some cases, employing alternative topological features for defining a volume portion to be removed.

The remaining volume portions of the NC model 32 that need to be removed can be defined as Step machining features. For example, FIGURES 11A and 11B illustrate a Step machining feature 128, herein named Front Step, having a single chain of hard walls 130 that includes surfaces 130a, 130b, and 130c. The Step feature 128 further includes a single chain of soft walls 132 including surface 132a and 132b, and a hard floor 134 subtended by a closed loop formed by the chain of hard walls 130 and the chain of soft walls 132. In addition, the Step feature 128 includes a soft top 136, which

is a portion of the floor of the Step feature 88, defined earlier, subtended by the walls 130 and 132. FIGURE 11C illustrates the NC model 32 after removal of the Step feature 128, indicating the volume portions remaining to be removed as dark sections. These volume portions include a portion 138 and a portion 140. The portion 138 includes a prism-like section 138a and a ledge section 138b.

As shown in FIGURES 12A and 12B, the portion 140 can be defined as a Step machining feature, herein named Back Step, by choosing a surface 142 as the hard floor of the feature. Upon such a selection, the method chooses surfaces 144a, 144b, and 144c to be the hard walls of the Step feature 140, and chooses surfaces 146a and 146b to be its soft walls. Finally, the method selects a surface 148 (shown as a hatched area), which is a portion of the hard floor of the Face feature defined above, as the soft top of the Step feature 140. FIGURE 12B, which is a fragmentary top plan view of the NC model 32, better illustrates the geometrical relationships among the hard and the soft walls of the Step machining feature 140, and FIGURE 12C illustrates the NC model 32 after removal of the Step feature 140.

Conventional CAM systems have no inherent knowledge of hard or soft walls. They simply assume by default that no boundary is to be crossed by the cutting tool. Thus, a user of such conventional systems has to either laboriously locate the tool correctly for entry and/or exit into the workpiece, or to modify what the system provides. This time-consuming, and in most cases does not provide an tool path of optimal efficiency.

With reference to FIGURES 13A and 13B, the prism-like section 138a that needs to be removed can be defined as a Step machining feature having a triangular hard floor 150, a hard wall 152, two soft walls 154 and 156, and a triangular soft top 158, which is a portion of the floor of the Face feature 68 defined above. FIGURE 13B shows that the hard wall 152 and the soft walls 154 and 156 form a closed loop that has a triangular cross-section.

FIGURE 13C illustrates the NC model 32 after removal of the prism-like feature 138a.

Referring again to FIGURE 11C, the ledge section 138b can also be defined as a Step machining feature, as shown in FIGURES 14A and 14B, having a single chain of hard walls 160 including surfaces 160a,160b, and 160c, and a single chain of soft walls including surfaces 162a and 162b. FIGURE 15A illustrates the NC model 32 after removal of the ledge section 138b, depicting the remaining volume portions 164 that need to be removed as dark sections. These volume portions can be defined as a Hole Pattern feature. Removal of the volume portions produces the NC model 32, as shown in FIGURE 15B.

Upon defining the volume portions to be removed as a plurality of machining features, the machinist can employ the method of the invention to create tool paths for machining the defined features. The method of the invention advantageously provides specific tool path strategies for machining the defined features. In particular, the method of the invention employs information regarding the soft surfaces of a machining feature to define a path for entry of a tool bit into a volume portion represented by the machining feature. As an illustrative example, FIGURE 16 shows a path 164 that an exemplary tool bit 164a, such as a milling bit, must traverse to machine the Step machining feature 88, defined above.

FIGURE 16B, which is a top view of the toolpath 164, illustrates that the soft walls 84a and 84b provide surfaces for entry and/or exit of the toolbit 164a into the Step feature 88. That is, the motion of the tool bit 164a along the tool path 164 begins and ends outside the soft walls 84a and 84b. Further, the tool bit 164a follows along the chain of hard walls 82 without cutting into the hard walls. Thus, the exemplary tool path 164 provides complete removal of the soft walls without affecting the hard walls. Those skilled in the art will understand that tool paths other than the tool path 164 can be employed to machine the Step feature 88.

The above illustrative embodiment shows that the method of the invention advantageously allows a human machinist to decide what types of machining features to utilize to define volume portions of a workpiece that need to be removed, to obtain a desired object. Further, the method of the invention advantageously creates these

features by requiring minimal geometrical selections, e.g., selecting the hard floor of a feature, from the machinist. Thus, the method of the invention provides advantages over conventional CAM systems, or feature-based systems that require manual feature creation, by greatly reducing the time and effort required to specify the material to be removed from the workpiece. Further, the features created by the method of the invention contain more machining information than those created with conventional systems. For example, the soft walls of a feature created by the method of the invention provide safe and efficient routes for entering and exiting the workpiece with a cutting tool. Further, the method of the invention advantageously ensures that all soft walls are completely machined away, which is not the case with most conventional systems.

FIGURE 17 illustrates a dialogue box 166 containing a list 166a of some of the above machining features created interactively by the machinist, as described above. While most GNC and Feature Recognition systems typically limit or do not allow the machinist to choose the order in which various volume portions of the work piece are to be removed, the method of the invention advantageously allows the machinist to choose the order in which the defined machining features are machined to create the desired object. For example, the method of the invention allows the machinist to change the order of the items on the list 166a. This advantageously allows the machinist to employ prior machining experience and knowledge of the machining environment, such as the capability of the machine tool to be used, the orientation of the work piece on the machine, and the program zero, to define an optimal sequence for removal of the defined machining features.

A number of topological features provided by the present invention can be defined in alternative ways. For example, the Profile feature 98 employed in the above illustrative embodiment includes a single chain of soft walls and a single chain of hard walls that together form a closed loop. FIGURE 18A illustrates that a Profile feature can, alternatively, include a single chain of soft walls and a single chain of hard walls that do not intersect, and where the hard walls together form a closed loop and the soft walls together form a closed loop. In particular, FIGURE 18A illustrates the design model 28 entirely enclosed within a workpiece 168. A machinist can define the volume element that needs to be removed from peripheral surfaces 168a, 168b, 168c, and 168d

of the workpiece 168 as a Profile feature in the following way. The machinist can choose the Profile feature icon 52 from the toolbar 34 (FIGURE 4), and subsequently select a surface 28a of the design model 28 to be one of the hard walls of the volume element to defined as a Profile feature. Upon such a selection by the machinist, the method of the invention defines a Profile feature that includes a single chain of hard walls including the peripheral surfaces 28a, 28b, 28c, 28d, 28e, 28f, and 28g of the design model 28 that together form a closed loop; and further includes a single chain of soft walls 168a, 168b, 168c, and 168d of the workpiece 168. The hard walls do not intersect with any of the soft walls. Further, each chain of walls, i.e., soft and hard, forms a closed loop. Further, this Profile feature has a soft top 168e, which is a portion of the top surface of the workpiece 168 subtended by the hard walls and the soft walls; and has a soft floor 168f, which is a portion of the bottom surface of the workpiece 168 subtended by the soft walls and the hard walls.

FIGURE 18B illustrates the work piece 168 after removal of this Profile feature.

With reference to FIGURES 4, 19A and 19B, another topological feature provided by the present invention is a Slot feature, which can be selected by choosing the icon 42 from the toolbar 34 . A Slot feature includes a hard floor and a soft top. As described above, under a first set of conditions, a Slot feature can include multiple alternating chains of hard and soft walls that together form a closed loop, and where only two chains of each type, i.e., hard or soft, are present; and one chain of hard walls is a normal constant offset of the other chain. FIGURE 19A, depicting an NC model 170, including a design model 172 and a parallelepiped work piece 174, illustrates a Slot machining feature 176 that a machinist can define by selecting a surface 172a of the design model 172 as the floor of the Slot machining feature 176.

Upon such a selection, the method of the invention defines surfaces 172b and 172c, which are constant offset of each other, as the hard walls of the Slot feature 176; and defines a portion of a surface 174a of the workpiece 174 subtended by the hard floor 172a and the hard walls 172b and 172c, as one of the soft surfaces of the Slot feature 176. To find the other soft surface of the Slot feature 176, the method of the invention extends the hard walls 172b and 172c and the floor 172a in one direction until they

intersect a surface 174b of the workpiece 174. The intersection defines a portion of the surface 174b that is subtended between the extended hard walls 172b and 172c and the hard floor 172a as the other soft surface of the Slot feature 176. The geometrical juxtaposition of the surfaces of the Slot feature 176 are better illustrated in FIGURE 19B, which is a top plan view of the Slot feature 176. In particular, FIGURE 19B illustrates the two hard walls 172b and 172c are normal constant offset of each other, and further illustrates the two soft walls 174a and 174b of the Slot feature 176.

FIGURE 19C illustrates the NC model 170, with the Slot machining feature 176 removed.

A Slot feature can alternatively include one chain of soft walls and three chains of hard walls that together form a closed loop. The chain of hard walls opposite the chain of soft walls must be a full radius, i.e., it must have a generally semi-cylindrical shape, and the remaining two chains of hard walls must be normal offset of each other. FIGURE 20A, a fragmentary view of the NC model 170 of Figure 19A, illustrates such a Slot machining feature 178. To build the Slot machining feature 178, a machinist selects a surface 170a of the NC model 170 as the hard floor of the feature. Upon such selection of the hard floor, the method of the invention selects two surfaces 170b and 170c, which are normal constant offset of each other, as two hard walls of the Slot feature 178. Further, the method of the invention selects a semi-cylindrical surface 170d as another hard wall of the Slot feature 178, and further selects a surface 170e opposite the semi-cylindrical surface 170d as a soft wall of the feature 178. In addition, the method of the invention selects a portion 174c of the upper surface of the workpiece subtended the walls 170b, 170c, 170d, and 170e as the soft top of the Slot feature 178.

FIGURE 20B, which is a top plan view of the Slot feature 178, illustrates the three hard walls 170b, 170c, and 170d in combination with the soft wall 170e form a closed loop; and further illustrates that the two hard walls 170b and 170c are normal constant offset of each other. Further, Figure 20B shows that the hard wall 170d is of full radius and is positioned opposite the soft wall 170e. FIGURE 20C depicts a portion of the NC model 170 after removal of the Slot feature 178.

According to yet another definition, a Slot feature includes four chains of hard walls that together form a closed loop. Two of these chains that are opposite to each other must each be a full radius with a radius of curvature equal to that of the opposite wall. The remaining two chains of hard walls must be normal constant offset of each other. FIGURES 21A and 21B, which are fragmentary views of an NC model 180 including a design model 182 enclosed within a workpiece 184, illustrate such a slot machining feature 186. A machinist can select a surface 182a of the design model 182 as the hard floor of the Slot feature 186. Upon such a selection, the method of the invention builds the Slot feature 186 by selecting two surfaces 182b and 182c, which are normal constant offset of each other, as two of the hard walls of the Slot feature 186. Further, the method selects two opposite surfaces 182d an 182e as the other two hard walls of the Slot feature 186. In addition, the method of the invention selects a portion 184a, subtended by the intersection of the walls 182b, 182c, 182d, and 182e with a top surface of the workpiece 184, as the soft top of the feature 186.

FIGURE 21C, which is a fragmentary top plan view of the Slot feature 186, better illustrates that the two surfaces 182d and 182e are each a full radius, and the two surfaces 182b and 182c are normal constant offset of each other. Those skilled in the art will understand that while two surfaces of such a Slot feature must each be a full radius, the other two surfaces can have any shape so long as they are normal constant offset of each other. FIGURE 21D shows a portion of the NC model 180 with the slot feature 186 removed.

Another topological feature provided by the present invention is a Channel feature. An illustrative example of such a Channel feature is shown in FIGURES 22A, 22B, and 22C. In particular, FIGURE 22A illustrates an NC model 188 having a design model 190 enclosed within a parallelepiped work piece 192. After defining a Pocket feature and a Thru_Pocket feature to represent a volume portion corresponding to a central opening 190a of the design model, a Channel feature 194 can be defined that includes chains of both hard walls 194a, 194b, 194c, 194d, 194e, 194f, 194g, 194h, 194i, 194j and soft walls 194k and 194l. Each of the chains 194a, 194c, 194e, 194g, 194h, and 194I includes a number of walls that are not individually labelled herein. The Channel feature 194 further includes a hard floor 194m subtended by the walls of the

channel feature 194, and includes a soft top that is contiguous with the top surfaces of pads 190b, 190c, 190d, 190e, 190f, and 190g. FIGURE 22C illustrates the NC model 188 with the Channel feature 194 removed.

Another topological feature provided by the method of the present invention is a Hole Pattern feature. A Hole Pattern feature may include either a hard floor or a soft floor, but each hole in the feature must necessarily include a soft top. To define a volume portion of an NC model as a Hole Pattern feature, a machinist selects the icon 56 from the toolbar 34 (FIGURE 4). Upon such a selection, a dialogue box 56a, as shown in FIGURE 23, appears that prompts the machinist to choose one or more of four options for selecting the holes to be included in the Hole Pattern. These options include selecting the holes (1) by their diameters, (2) all holes on a selected surface, (3) by a user specified parameter, or (4) by individual selection. If option (1), i.e., Diameter, is selected, the user chooses one or more diameters from a system generated list of the diameters of all holes found on the model. All holes of the specified diameter(s) are selected. If option (2), i.e., Surface, is selected, the user chooses one or more surfaces from the model. All holes that the system finds on the selected surface(s) are selected. If option (3), i.e., Parameter, is selected, the user will specify the name of a parameter, e.g., “B-holes”. The system will select all holes on the model that possess the specified parameter. If option (4), i.e., Axes, is selected, the user will choose the axes of individual holes to be included in the Hole Pattern feature. This selection can be made graphically or from a system-generated list. Further, two or more of these options can be used together to narrow down the search. For example, the user can ask the system to select all holes having a diameter of 0.25 inch that lie on a specific surface to be selected.

As an illustrative example of a Hole Pattern feature, FIGURE 24A shows an NC model 196 having a Hole Pattern machining feature 198 that includes four holes 198a, 198b, 198c, and 198d therein. Each hole has a single cylindrical hard wall and a soft top. Further, each hole extends through the entire width of the NC model 196, and hence has a soft floor. Those skilled in the art will understand that it is also possible to have a Hole Pattern having holes with hard floors.

FIGURE 24B illustrates the NC model 196 with the Hole Pattern feature 198 removed.

A Slab feature is another topological feature provided by the method of the present invention. As discussed above, a Slab feature includes a hard floor and a soft top, and further includes some hard walls and some soft walls. As an illustrative example of a Slab feature, FIGURES 25A and 25B show an NC model 200 that includes a design model 202 enclosed within a workpiece 204. To define a volume portion to be removed from the workpiece 204 as a Slab feature, the machinist selects a surface 202a of the design model 202 as the hard floor of the Slab feature to be created. Upon such a selection, the method of the invention finds surfaces 204a, 204b, 204c, 204d, 204e, and 204f of the workpiece 204, forming two open loops, as the soft walls of the Slab feature. In addition, the method finds semi-circular surfaces 202b and 202c and surfaces 202d and 202e, each forming a closed loop, as the hard walls of a Slab feature 206. A portion 204i of the top surface of the workpiece 204 subtended by the hard and the soft walls forms a soft top of the Slab feature 206. In this illustrative example, each of the hard walls 202d and 202e forms an island that is fully contained on the floor of the feature.

FIGURE 25C illustrates the NC model 200 with the Slab feature 206 removed.

Another topological feature that the method of the invention provides is an Entry Hole. With reference to FIGURES 4, 26A, and 26B, the machinist can create an Entry Hole feature by selecting the icon 58 from the tool bar 34 to obtain a dialogue box 58a. The dialogue box 58a prompts the machinist to choose a desired diameter for the hole. Further, the machinist indicates in which existing feature, the hole is to be created. The features that are selectable include a Pocket feature, a Thru_Pocket feature, an O-ring Groove feature, and a Slot feature having four chains of hard walls which together form a closed loop. An Entry Hole has a single, cylindrical, hard wall, a soft top, and either a hard or a soft floor, depending on whether the hole extends completely through the work piece.

FIGURE 26B illustrates an exemplary Entry Hole feature 208 with a hard floor, created in a Pocket feature. The Entry Hole feature 208 advantageously facilitates the

entry of a tool bit, such a milling cutter, into the Pocket feature. In particular, the Entry Hole 208 is drilled in the workpiece prior to milling the Pocket feature to allow entry of the cutter into the workpiece to mill the Pocket feature.

Another topological feature provided by the method of the present invention is a Flange Face feature. A machinist can select the icon 50 form the toolbar 34 (FIGURE 4) to obtain a dialogue box 54a, as shown in FIGURE 27A, with the Define Feature Floor option preferably preselected The dialogue box 54a prompts the machinist to select a surface of the design model to be the hard floor of the feature. Upon such a selection, the method of the invention finds one closed loop of soft walls as the outer boundary of the feature, and further finds either one closed loop of soft walls or one closed loop of hard walls to constitute the inner boundary of the feature. FIGURES 27B and 27C illustrate an exemplary Flange Feature 210 in an NC model 212, where the feature includes a closed loop of soft walls 210a as its outer boundary, and a closed loop of soft walls 210b as its inner boundary.

FIGURE 27D illustrates the NC model 212 with the Flange Face feature 210 removed.

Another topological feature that the method of the invention provides is a Thru_Slot feature. A Thru_Slot feature includes a soft floor and a soft top. In one form, a Thru_Slot feature includes one chain of soft walls and three chains of hard walls, where the soft walls and the hard walls together form a closed loop, and the chain of hard walls opposite the chain of soft walls is a full radius. FIGURE 28A illustrates that a machinist can define a Thru_Slot feature 214 in a design model 216 by selecting a hard wall 214a of the design model 216. Upon such a selection, the method of the invention builds the Thru_Slot feature 214 by finding two additional hard walls 214b, and 214c, a soft wall 214d, a soft floor 214e, and a soft top 214f. FIGURE 28B, which is a top view of the Thru_Slot feature 214, shows that the hard walls 214b and 214c are constant offset of each other, and the hard wall 214a, opposite the soft wall 214b, is a full radius. Those skilled in the art will understand that the hard walls 214b and 214c can have any shape so long as they are constant offset of each other.

FIGURE 29 illustrates the design model 216 after removal of the Thru_Slot feature 214.

An alternative Thru_Slot feature 218 in the design model 216, shown in FIGURE 30A, includes two chains of hard walls 220 and 222 that are normal constant offset of each other, where the chain 220 includes surfaces 220a, 220b, and 220c; and the chain 222 includes surfaces 222a, 222b, and 222c. The Thru_Slot feature 218 further includes two hard walls 224 and 226, where each is a full radius. In addition, the Thru_Slot feature 218 has a soft top 228, which is a portion of the upper surface of the design model 216 subtended by the walls of the feature 218, and has a soft floor 230, which is a portion of the lower surface of the design model 216 subtended by the walls of the feature 218. The method of the invention constructs the Thru_Slot feature 218 upon selection of a surface of the design model 216, such as the surface 222b, to be one hard surfaces of the feature 218.

FIGURE 30B illustrates the design model 216 after removal of the Thru_Slot feature 218.

A Boss Top topological feature provided by the invention includes a hard floor, a soft top, and a single chain of soft walls that together form a closed loop. FIGURE 31B illustrates an exemplary Boss Top feature 232 according to the teachings of the present invention, created within a previously formed pocket feature 234a of an NC model 234. The machinist can create the Boss Top feature 232 by selecting the icon 54 from the toolbar 34 (FIGURE 4). Upon such a selection, the method of the invention presents a dialogue box 54a, shown in FIGURE 31A, to the machinist that prompts the machinist to choose a surface of the design model 234 as the hard floor of a volume portion to be defined as a Boss Top machining feature. In this exemplary illustration, the machinist selects a horizontal surface 232a to be the hard floor of the Boss Top feature 232. Upon such a selection, the method of the invention chooses a cylindrical soft wall 232b, and a soft top 232c as the other surfaces of the Boss Top feature 232. Although the soft wall 232b in this exemplary illustration is cylindrical, those skilled in the art will understand that the soft wall 232b can have any desired shape.

FIGURE 31C illustrates the design model 234 after removal of the Boss Top feature 232.

Another topological feature according to the teachings of the present invention is an O-Ring Groove. An O-Ring Groove includes a hard floor and a soft top, and further includes two chains of non-intersecting hard walls, where each chain is a normal constant offset of the other, and each chain forms a closed loop. FIGURE 32A illustrates an exemplary O-Ring Groove machining feature 236 of the invention in an NC model 238. To create the O-Ring Groove feature 236, the machinist chooses a surface 238a of the design model 238 as the hard floor of the feature 236. Upon such a selection, the method of the invention selects a chain of hard walls 238b, another chain of hard walls 238c, and a soft top 238d, to form the feature 236. FIGURE 32B, which is a top view of the O-Ring Groove 236, illustrates that the chain of walls 238b and the chain of walls 238c are normal constant offset of teach other, and further illustrates that each chain of hard walls forms a closed loop.

FIGURE 32C illustrates the design model 238 after removal of the O-Ring Groove 236.

Another topological feature taught by the present invention is an Open Contour feature that includes a hard floor and a soft top. The hard floor of an Open Contour feature is either a non-planar surface, or is a planar surface that is not normal to the spindle of the machine tool, i.e., a canted surface. FIGURE 33 illustrates a volume element 240a of an NC model 240, which volume element is shown as detached from another portion of the design model for clarity, that is defined as an Open Contour feature according to the teachings of the present invention. In particular, the Open Contour feature 240a includes a user-selected hard canted floor 240b, three peripheral soft walls, two of which 240c and 240d are shown, a hard wall 240e, and a soft top 240f.

An Undercut topological feature according to the invention includes a hard top, and a floor that can be either hard or soft. Further, an Undercut feature includes a chain of hard walls and a chain of soft walls that together form a closed loop. As an

exemplary illustration of an Undercut feature, FIGURE 34 shows a design model 242, a volume portion 244 of which has been removed. The removed portion was defined as an Undercut machining feature having a hard top 244a, soft walls 244b, 244c, and 244d, a hard wall 244e, and a hard floor 244f.

A Top Chamfer is another topological feature provided by the method of the invention, and includes a hard floor, and a soft top. Further, a Top Chamfer includes a chain of soft walls that can form either an open or a closed loop. FIGURE 35A illustrates a design model 246 enclosed within a parallelepiped workpiece 248. A volume portion 250 of the work piece 248 to be removed to produce a chamfer 252, as shown in FIGURE 35B, is defined as a Top Chamfer machining feature having a hard floor 250a, which is the surface of the chamfer 252, a soft top 250b, which is a portion of the upper surface of the work piece 248, and soft walls 250c, 250d, and 250e that form an open loop.

With reference to FIGURES 36A and 36B, another chamfer 254, surrounding an opening 256, can be produced by defining a volume portion 258 surrounding an earlier-formed Thru_Pocket feature 256 as a Top Chamfer machining feature. The Top Chamfer feature 258 includes a hard floor, which is the surface of the chamfer 254, a soft top 258a, which is a portion of the top surface of the workpiece 248, and a closed-loop chain 258b of soft walls.

FIGURE 37 illustrates a volume portion 260, removed from the peripheral edge of a Pocket feature 262 formed in a workpiece 264, to produce a Round feature 266. The removed volume portion 260 is defined as a Top Round machining feature, according to the teachings of the present invention, having a hard floor, which is the surface of the Round feature 266 itself, a soft top 260a, which is a portion of the top surface of the workpiece 264, and a chain 260b of soft walls forming a closed loop. FIGURE 37 further shows another volume portion 268 removed from an edge of the work piece 264, to produce another Round feature 270. The volume portion 268 can also be defined as a Top Round machining feature having the surface of the Round feature 270 as its hard floor, and further having a soft top 270a, and a chain 270b of soft walls that form an open loop.

Another topological feature according to the present invention is a Rib Top feature. For example, FIGURE 38A illustrates a volume portion 272, defined as a Rib Top machining feature, removed from a workpiece to produce a Rib design feature 274 in a design model 276. The Rib Top feature 272 includes a hard floor 272a, which is a surface of the design model 276, one chain of soft walls 272b, and another chain of soft walls on the opposite side of the chain 272 (not visible). Further, the Rib Top feature 272 includes hard walls at its both ends, one of which, i.e., a hard wall 272c, is visible.

FIGURE 38B illustrates another Rib Top feature 278 in a design model 280, created by removing a volume portion 282, which is defined as a Rib Top machining feature in accordance with the teachings of the present invention. The Rib Top feature 282 includes a hard floor 282a, which is a surface of the design model 280. The remaining surfaces of the Rib Top feature 282 are soft surfaces, such as surfaces 282b, 282c, 282d, and a soft wall opposite to the wall 282b (not visible).

As another example of a Rib Top feature, FIGURE 38C illustrates a volume portion 284, defined as a Rib Top feature, that is removed from a workpiece to create a free-form Rib Top design 286. The Rib Top feature 284 includes a hard floor 284a, a soft top 284b, and soft walls 284c and 284d. Further, the Rib Top feature 284 includes another soft wall (not visible) opposite the wall 284c.

While the present invention has been described with reference to above illustrative embodiments, those skilled in the art will appreciate that various changes in form and detail may be made without departing from the intended scope of the present invention as defined in the appended claims.

CLAIMS

1. A computer-aided method for machining a work piece to produce a physical object, said method comprising the steps of:

providing a solid model of the object and a solid model of the work piece by employing graphical software,

combining said model of the object with said model of the work piece to produce a numerical control model depicting volume portions of said work piece to be removed to create said object,

providing a plurality of topological feature types in said software,

partitioning said volume portions to be removed into a plurality of machining features, wherein each machining feature is produced by having a human user choose one of said plurality of feature types and a surface of said numerical model to associate a portion of the model having said surface with said chosen feature type to define said each machining feature, and

providing tool paths for machining each of said machining features.

2. The method of claim 1, wherein said step of partitioning includes forming said each machining feature after selection of a surface of said numerical model by the human user.

3. The method of claim 1, wherein said graphical software is a CAD system.

4. The method of claim 1, further including the step of selecting said plurality of topological features from the group consisting of a Face and a Slab and a Pocket and a Thru_Pocket and a Step and a Profile and a Channel and a Slot and a Boss Top and a Flange Face and a Hole Pattern and an Entry Hole and a Thru_Slot and an Undercut and a Rib Top and a Top Chamfer and a Top Round and an Open Contour and a O-Ring Groove.

5. The method of claim 4, wherein said Face feature includes a hard floor, a soft top, and a single chain of soft walls.

6. The method of claim 4, wherein said Slab feature includes a hard floor, a soft top, and hard and soft walls.

7. The method of claim 4, wherein said Pocket feature includes a hard floor, a soft top, and a single chain of hard walls forming a closed loop.

8. The method of claim 4, wherein said Thru_Pocket feature includes a soft floor, a soft top, and a single chain of hard walls forming a closed loop.

9. The method of claim 4, wherein said Step feature includes a hard floor, a soft top, a single chain of soft walls, and a single chain of hard walls.

10. The method of claim 4, wherein said Profile feature includes a soft floor, a soft top, a single chain of soft walls, and a single chain of hard walls.

11. The method of claim 4, wherein said Channel feature includes a hard floor, a soft top, and multiple alternating chains of hard and soft walls forming a closed loop.

12. The method of claim 1, wherein the step of combining includes superimposing said model of the object on said model of the workpiece.

13. A computer-aided method for representing volume portions of an NC model by a plurality of machining features, said method comprising the steps of:

providing a plurality of topological feature types,

selecting for each volume portion of the NC model at least one of said topological feature types and at least a surface of the volume portion to build a machining feature representing the volume portion having the selected surface.

14. The method of claim 13, further including the step of selecting said plurality of topological features from the group consisting of a Face and a Slab and a Pocket and a Thru_Pocket and a Step and a Profile and a Channel and a Slot and a Boss Top and a

Flange Face and a Hole Pattern and an Entry Hole and a Thru_Slot and an Undercut and a Rib Top and a Top Chamfer and a Top Round and an Open Contour and an O-Ring Groove.

15. A CAM system for assisting a human machinist in machining a work piece to produce an object, comprising

a solid model of the work piece,

a solid model of the object,

means for combining said model of the work piece with said model of the object to produce a numerical control model depicting volume portions of said work piece to be removed to create said object,

means for defining a plurality of topological feature types for partitioning volume portions of said numerical control model into a plurality of machining features, wherein said machinist selects said volume portions and selects at least one of said plurality of feature types to be employed to represent each of said volume portions,

means for producing tool paths for machining said plurality of machining features.

16. The CAM system of claim 15, wherein a CAD system is used to produce said models.

17. The CAM system of claim 15, wherein said plurality of topological feature types are selected from the group consisting of a Face and a Slab and a Pocket and a Thru_ Pocket and a Step and a Profile and a Channel and a Slot and a Boss Top and a Flange Face and a Hole Pattern and an Entry Hole and a Thru_Slot and an Undercut and a Rib Top and a Top Chamfer and a Top Round and an Open Contour and a O-Ring Groove.

18. A computer readable medium holding computer-executable instructions for assisting a human machinist in machining a work piece according to a method comprising the steps of:

producing a solid model of the object and a solid model of the work piece,

combining said model of the object with said model of the work piece to produce a numerical control model depicting volume portions of said work piece to be removed to create said object,

providing a plurality of topological feature types,

partitioning said volume portions to be removed into a plurality of machining features, wherein each machining feature is produced by having the human machinist choose one of said plurality of feature types and a surface of said numerical model to associate a volume portion of said model having said surface with said chosen feature type to define a machining feature, and

providing tool paths for machining each of said machining features.

19. The computer-readable medium of claim 18, wherein said plurality of topological feature types is selected from the group consisting of a Face and a Slab and a Pocket and a Thru_Pocket and a Step and a Profile and a Channel and a Slot and a Boss Top and a Flange Face and a Hole Pattern and an Entry Hole and a Thru_Slot and an Undercut and a Rib Top and a Top Chamfer and a Top Round and an Open Contour and a O-Ring Groove.

20. The computer-readable medium of claim 18, wherein said computer-readable medium includes a CD-ROM.

21. The computer-readable medium of claim 18, wherein said computer-readable medium includes a floppy disk.

22. The computer-readable medium of claim 18, wherein said computer-readable medium includes a hard disk.

23. In a computer platform, a transmission medium for transmitting computer-executable instructions for performing a method for assisting a human machinist in machining a work piece to produce an object, said method comprising the steps of:

producing a solid model of the object and a solid model of the work piece,

combining said model of the object with said model of the work piece to produce a numerical control model depicting volume portions of said work piece to be removed to create said object,

providing a plurality of topological feature types,

partitioning said volume portions to be removed into a plurality of machining features, wherein each machining feature is produced by having the human machinist choose one of said plurality of feature types and a surface of said numerical model to associate a volume portion of said model having said surface with said chosen feature type to define a machining feature, and

providing tool paths for machining each of said machining features.

24. A computer readable medium holding executable instructions for defining a plurality of topological feature types selected from the group consisting of a face and a slab and a pocket and a through pocket and a step and a profile and a channel and a slot and a boss top and a flange face and a hole pattern and an entry hole and a through slot and an undercut and a rib top and a top chamfer and a top round and an open contour and a O-Ring Groove.

25. In a computer system, a graphical user interface for allowing a user to choose at least one of a plurality of topological feature types to define selected volume portions of a solid model.

26. The graphical user interface of claim 25, wherein said solid model is produced by a CAD system.

27. The graphical user interface of claim 25, wherein said topological feature types are selected from the group consisting of a Face and a Slab and a Pocket and a Thru_ Pocket and a Step and a Profile and a Channel and a Slot and a Boss Top and a Flange Face and a Hole Pattern and an Entry Hole and a Thru_Slot and an Undercut and a Rib Top and a Top Chamfer and a Top Round and an Open Contour and a O-Ring Groove.

28. A computer readable medium holding computer-executable instructions for assisting a human machinist in machining a work piece represented by a solid model to produce an object represented by a solid model, said two solid models being combined to create an NC mode depicting volume portions of said work piece to be removed to create said object, according to a method comprising the steps

providing a plurality of topological feature types,

partitioning said volume portions to be removed into a plurality of machining features, wherein each machining feature is produced by having the human machinist choose one of said plurality of feature types and a surface of said NC model to associate a volume portion of said model having said surface with said chosen feature type to define a machining feature, and

providing tool paths for machining each of said machining features.

29. A computer-aided method for machining a workpiece to produce a physical object, substantially as herein described with reference to and as illustrated in the accompanying drawings.

30. A computer-aided method for representing volume portions of an NC model by a plurality of machining features, substantially as herein described with reference to and as illustrated in the accompanying drawings.

31. A CAM system substantially as herein described with reference to and as illustrated in the accompanying drawings.

32. A graphical user interface substantially as herein described with reference to and as illustrated in the accompanying drawings.

33. A computer program for implementing the method claimed in any of claims 1 to 14, 29 and 30.

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Application No: GB 0022169.7
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Examiner: Dave Mobbs
Date of search: 6 February 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): G3N NGBC4.

Int Cl (Ed.7): G05B 19/409, 19/4093, 19/4097.

Other: ONLINE: EPODOC, JAPIO, WPI.

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0,604,661 A	(FANUC LTD.)	
X	US 5,465,215	(CINCINNATI MILACRON INC.)	13, 14, 28.

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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